Vol. XVII & Issue No. 10 October - 2024
INDUSTRIAL ENGINEERING JOURNAL

NOVEL DESIGN OF CYCLOCONVERTOR FOR REDUCING AVAILABLE SUPPLY FREQUENCY TO ONE THIRD OF ITS VALUE

V. Malhotra
J D College of Engineering and Management, Nagpur 441501, India

P. B. Maheshwary
Dean, Faculty of Science and Technology, R T M Nagpur University, Nagpur

J. P. Modak
J D College of Engineering and Management, Nagpur 441501, India

P N Belkhode
Laxminarayan Institute of Technology, R T M Nagpur University, Nagpur
Email: pnbelkhode@gmail.com

N. N. Gyanchandani
J D College of Engineering and Management, Nagpur 441501, India

Abstract

The present-day approach to evolve step down cycloconvertor circuit as to only convert time period of available supply without giving much considerations to required RMS value of voltage. The objective of this paper essentially is to overcome this shortcoming of circuit for step down cycloconverter. The single phase to single phase conversion is considered which precipitates a novel electrical cum electronic circuit to precisely meet the objective. The development is achieved mainly by making use of a mathematical treatment for harmonic analysis of converted periodically varying signal with 60 milli seconds as the time period. In other words, the available supply frequency of 50 c/s is converted to 1/3rd its value i.e. 16.66 c/s.

Keywords: Stepdown Cycloconvertor, VVF Drives, Soft start devices, switching circuit Harmonic analysis, Filter circuit, single phase transformer.

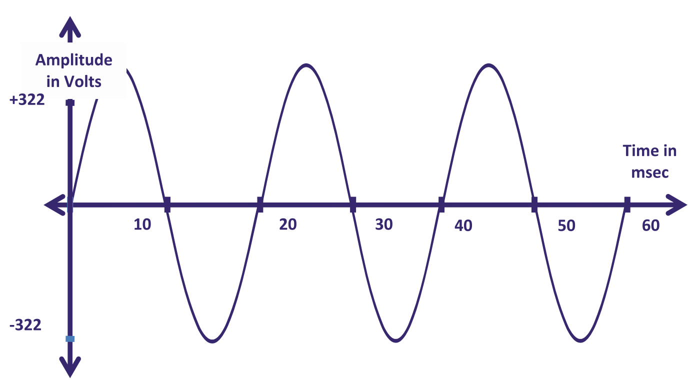
1. INTRODUCTION

Normally in the case of three phase ac induction motor drive, the storage torque characteristic is such that initially the generated torque drops to its minimum value, then it rises exponentially with reducing rate to maximum value, then it drops exponentially to its full load value. In many of the process machines, which initially need high torque demand, this induction motor torque characteristic is required to be modified. This is nothing but going in for development of soft start devices. The typical example of the application is medium duty belt conveyor used in mines and coal handling plants of thermal stations. In order to get the desired starting torque characteristic, it becomes necessary to change supply frequency, particularly reducing it so that the full load torque magnitude can increase. Similarly, there exists the requirement of converting the supply frequency in other applications such as traction drives, tram ways, electrically operated vehicles, etc. Upon performing the requisite literature survey, it is noticed that the development of cycloconvertor is on the following lines: Couple of sinusoidal cycles of available supply are gathered and converted into required time period. The converted supply only satisfies the enhancement of time period of supply. However, it doesn't guarantee the required RMS value. The present research work of design of cycloconvertor overcomes these limitations.

2. OBJECTIVE OF PRESENT RESEARCH AND BASIC CONCEPT OF SOLUTION

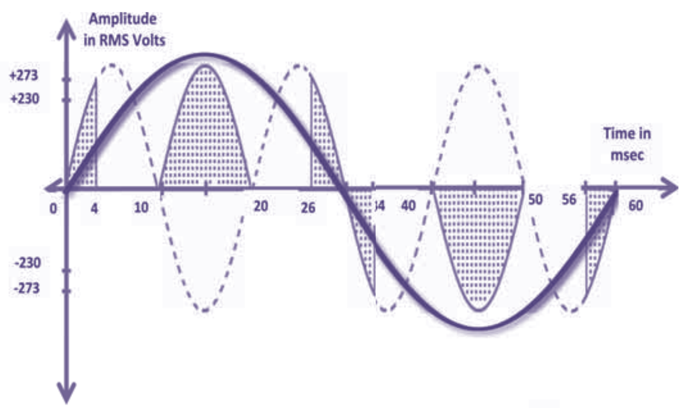
Figure 1 depicts available sinusoidal supply 230 V per phase RMS with frequency f = 50 cycles/sec. Figure 1 shows its three consecutive cycles. The purpose of the invention is to develop appropriate electronic cum electrical circuit which will convert this signal in to the one with 230 V RMS value and 16.66 cycles/sec frequency. This comes to conversion of three consecutive sinusoidal cycles into one sinusoidal cycle with the time duration of 60 milliseconds.

Figure 1. Available sinusoidal supply of 50 c/s with three cycles



The necessary alteration could be as depicted in Figure 2. Figure 2 shows that during 0 to 30 ms of converted signal there are three major intervals 0-4 ms in which original three cycles supply will be picked up by clipping the original sine wave, then in next 4-10 ms supply would be nil, then in next 10-20 ms original negative half cycle will be inverted, then in the next 20-26 ms the supply voltage would be zero and in the next 26-30 ms, portion of original 3 cycles will be clipped. Thus, original one and half consecutive sinusoidal cycles will be converted in to variation shown by dotted region during 0-30 ms in Figure 2. Regarding time variation 30-60 ms in Figure 2, original signal with 3 consecutive cycles would be clipped such that during 30-34 ms and during 56-60 ms original signal will be utilized as it is. As against this, during 40-50 ms the original signal will be inverted. The original three consecutive sinusoidal cycles signal will be converted as shown by dotted region in Figure 2.

Figure 2. Output waveforms



3. JUSTIFICATION FOR HARMONIC ANALYSIS OF CONVERTED SIGNAL

In order to realize above stated signal conversion necessary circuit is shown in Figure 3. In this figure, AB is a resistance through which a current is made to pass through, having the variation as depicted by dotted region in Figure 2. Thus the current flowing through the resistance AB is commensurate with voltage variation across AB as depicted by dotted region in Figure 2 and the value of the resistance chosen. The development reported so far concludes that potential across resistance AB is as per boundary of dotted portion of Figure 2. This is obviously a periodic variation with 60 ms period of one cycle.

3.1 Harmonic Analysis of Converted Signal: In order to realize our basic objective, it is inevitable to perform harmonic analysis of a voltage across AB with fundamental component having the frequency 16.66 cycles/second. The other components will have multiple frequencies with probably variable amplitudes. It is expected here that, the amplitude of fundamental component would be maximum but not obviously lesser than 230 volt RMS value. Hence, the system will need a single phase step-down transformer with appropriate turns ratio. The complete circuit would therefore be as described in Figure 3. The details of harmonic analysis are as under. Let us consider six time instants t_1=0.004 s, t_2=0.016 s, t_3=0.026 s, t_4=0.033 s, t_5=0.044 s, t_6=0.059 s in one cycle of expected signal.

The variation of instantaneous voltage is assumed to be of the form as under:

$V_t = V_{max}$ [sin(2πf)t] with f=50 cycles/second commensurate with available signal and to satisfy the initial condition i.e. at t=0 V_t=0. This is in accordance with Figure 2.

In this case for harmonic analysis, it is necessary to assume sine form of harmonic series because the initial conditions are at time t=0 s, the instantaneous voltage V_i is zero volts. In view of this initial condition, following analysis holds true.

F=50 Hz, t_1=0.004 s, Now, $V_{max} = \sqrt{2} * V_{rms}$ = 1.414*230 = 322.269 = 322 Volts

$$V_i = V_{max} \text{Sin}[(2\pi f)t] \quad (1)$$

Substituting, V_{max} = 322 Volts, f = 50 cycles/second and various time instants such as t_1=0.004 s, t_2=0.016 s, t_3=0.026 s, t_4=0.033 s, t_5=0.044 s, t_6=0.059 s during 60 ms time interval of converted signal one gets,

V_i= 322[Sin (314)*0.004], therefore, V_i= 306.17 volts

Similarly, V_{ii}, V_{iii}, V_{iv}, V_v, V_{vi} at t_2=0.016 s, t_3=0.026 s, t_4=0.033 s, t_5=0.044 s, t_6=0.059 s respectively would be V_{ii}=306.49 volts, V_{iii}=306.64 volts, V_{iv}= -259.50 Volts, V_v= -305.43 volts, V_{vi}= -102.37 volts. Now,

$$V_i = V_1 \sin(\omega_1 t) + V_2 \sin(\omega_2 t) + V_3 \sin(\omega_3 t) + V_4 \sin(\omega_4 t) + V_5 \sin(\omega_5 t) + V_6 \sin(\omega_6 t) \quad (2)$$

Now substituting for ω_1, ω_2, ω_3, ω_4, ω_5, ω_6 and for t_1=0.004 s, t_2=0.016 s, t_3=0.026 s, t_4=0.033 s,

t_5=0.044 s, t_6=0.059 s in Eq.(2) one arrives at six equations given as below:

$$V_i = V_1\sin(104.62*0.004) + V_2\sin(209.24*0.004) + V_3\sin(313.87*0.004) + V_4\sin(418.49*0.004) + V_5\sin(523.12*0.004) + V_6\sin(627.74*0.004) \quad (3)$$

$$V_{ii} = V_1\sin(104.62*0.016) + V_2\sin(209.24*0.016) + V_3\sin(313.87*0.016) + V_4\sin(418.49*0.016) + V_5\sin(523.12*0.016) + V_6\sin(627.74*0.016) \quad (4)$$

$$V_{iii} = V_1\sin(104.62*0.026) + V_2\sin(209.24*0.026) + V_3\sin(313.87*0.026) + V_4\sin(418.49*0.026) + V_5\sin(523.12*0.026) + V_6\sin(627.74*0.026) \quad (5)$$

$$V_{iv} = V_1\sin(104.62*0.033) + V_2\sin(209.24*0.033) + V_3\sin(313.87*0.033) + V_4\sin(418.49*0.033) + V_5\sin(523.12*0.033) + V_6\sin(627.74*0.033) \quad (6)$$

$$V_v = V_1\sin(104.62*0.044) + V_2\sin(209.24*0.044) + V_3\sin(313.87*0.044) + V_4\sin(418.49*0.044) + V_5\sin(523.12*0.044) + V_6\sin(627.74*0.044) \quad (7)$$

$$V_{vi} = V_1\sin(104.62*0.059) + V_2\sin(209.24*0.059) + V_3\sin(313.87*0.059) + V_4\sin(418.49*0.059) + V_5\sin(523.12*0.059) + V_6\sin(627.74*0.059) \quad (8)$$

In the above equations V_i to V_{vi} are the instantaneous values of voltages of finally converted signal at time instants t_1=0.004 s, t_2=0.016 s, t_3=0.026 s, t_4=0.033 s, t_5=0.044 s, t_6=0.059 s.

These equations can be obtained in matrix form. Later on performing necessary mathematical processing one can obtain the values of V_1=306.17, V_2= 306.49, V_3= 306.64, V_4= -259.50, V_5= -305.53, V_6= -102.37 volts as follows:

$$\begin{bmatrix} Vi \\ Vii \\ Viii \\ Viv \\ Vv \\ Vvi \end{bmatrix} = \begin{bmatrix} 0.91370 & 0.6697 & 0.3010 & -0.1029 & -0.4983 & -0.8076 \\ -0.1029 & -0.9788 & 0.3046 & 0.9160 & -0.4933 & -0.8144 \\ -0.9124 & 0.6665 & -0.3018 & -0.1145 & 0.5107 & -0.8177 \\ -0.9520 & 0.8128 & -0.59548 & 0.32120 & -0.0157 & -0.2908 \\ -0.10889 & -0.97628 & 0.32109 & 0.90644 & -0.5181 & -0.79379 \\ 0.99388 & 0.97563 & 0.94564 & 0.90397 & 0.8515 & 0.78848 \end{bmatrix} \text{x} \begin{bmatrix} V1 \\ V2 \\ V3 \\ V4 \\ V5 \\ V6 \end{bmatrix} \quad (9)$$

Time instant in second	B						A
0.004	0.91370	0.6697	0.3010	-0.1029	-0.4983	-0.8076	Vi
0.016	-0.1029	-0.9788	0.3046	0.9160	-0.4933	-0.8144	Vii
0.026	-0.9124	0.6665	-0.3018	-0.1145	0.5107	-0.8177	Viii
0.033	-0.9520	0.8128	-0.59548	0.32120	-0.0157	-0.2908	Viv
0.044	-0.10889	-0.97628	0.32109	0.90644	-0.5181	-0.79379	Vv
0.059	0.99388	0.97563	0.94564	0.90397	0.8515	0.78848	Vvi

$$\text{Let } A = \begin{bmatrix} Vi \\ Vii \\ Viii \\ Viv \\ Vv \\ Vvi \end{bmatrix} = \begin{bmatrix} 306.17 \\ 306.49 \\ 306.64 \\ -259.50 \\ -305.53 \\ -102.37 \end{bmatrix}, \; X = \begin{bmatrix} V1 \\ V2 \\ V3 \\ V4 \\ V5 \\ V6 \end{bmatrix} \text{ and}$$

$$B = \begin{bmatrix} 0.91370 & 0.6697 & 0.3010 & -0.1029 & -0.4983 & -0.8076 \\ -0.1029 & -0.9788 & 0.3046 & 0.9160 & -0.4933 & -0.8144 \\ -0.9124 & 0.6665 & -0.3018 & -0.1145 & 0.5107 & -0.8177 \\ -0.9520 & 0.8128 & -0.59548 & 0.32120 & -0.0157 & -0.2908 \\ -0.10889 & -0.97628 & 0.32109 & 0.90644 & -0.5181 & -0.79379 \\ 0.99388 & 0.97563 & 0.94564 & 0.90397 & 0.8515 & 0.78848 \end{bmatrix}$$

Therefore the equation 9 can be written as [A] = [B] * [X]

$[X] = [B^{-1}] \times [A]$, which on solving we get,

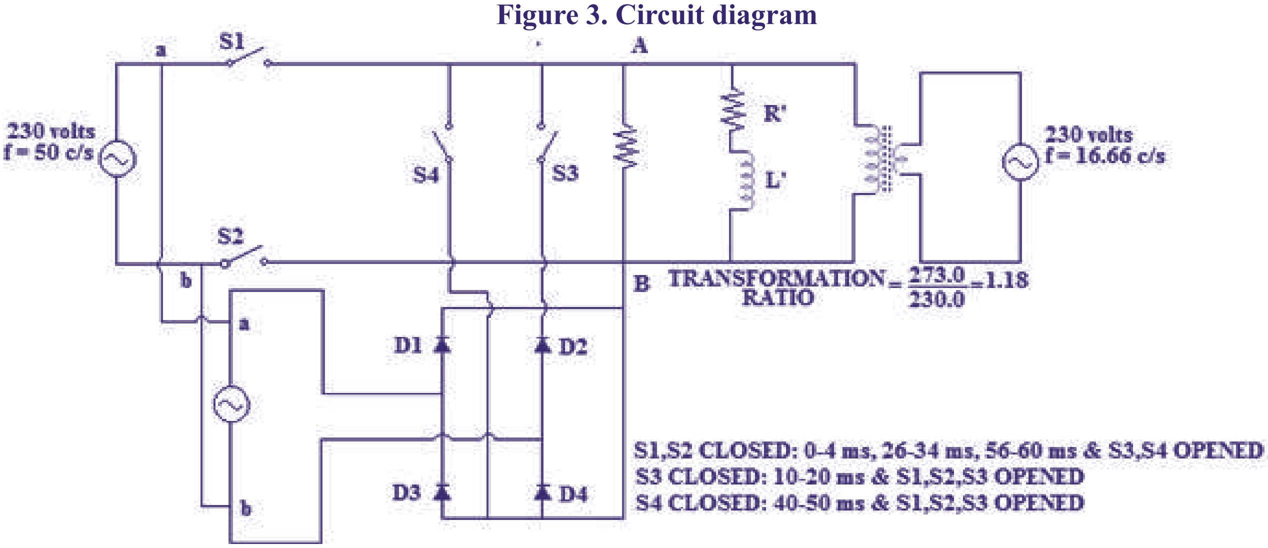
$V_1 = 386.044$, $V_2 = 22.933$, $V_3 = 113.054$, $V_4 = -16.96$, $V_5 = 47.9818$, $V_6 = 0.0991$

The above calculations precipitate that the finally converted signal has six harmonic components with rms values as 386.044 volts, 22.933 volts, 113.054 volts, -16.96 volts, 47.9818 volts, 0.0991 volts respectively for frequencies 16.66 cycles/second, (16.66 x 2) cycles/second, (16.66 x 3) cycles/second, (16.66 x 4) cycles/second, (16.66 x 5) cycles second, (16.66 x 6) cycles/second respectively. Obviously, our interest is in first harmonic component with 386.044 volts peak value and 16.66 cycles/second frequency from amongst these components. Off course at this stage one does not get the desired rms value of 230 volts.

1. NECESSITY OF FILTERING SOME HARMONICS AND DESIGN OF FILTER CIRUIT

One needs two devices 1) Filter circuit and 2) a step down transformer as shown in Figure 3. In Figure 3 the circuit consists of a diode bridge circuit which comprises of four diodes D_1, D_2, D_3, and D_4 is performing the task of inversion of original negative half cycle during 10-20 ms into positive half cycle by closing switch S_3 keeping other switches open. Whereas, for inverting positive half cycle during 40-50 ms of the original signal into negative we need to close switch S_4 keeping switches S_1, S_2 and S_3 open.

Figure 3. Circuit diagram



The Filter circuit could be a resistance R' in series with inductance L' such that the impedance imposed by this combination due to higher harmonic components is so high that the corresponding currents passing through this R'- L' combination is negligible. The calculations to evaluate R' and

L' are as below:

Design of Filter circuit:

$$I = V/[(R')^2 + (X'_L)^2]^{1/2} \quad (10)$$

Now in Eq.(10) V=386.04 Volts and assuming R = 1Ω and I = 2 Amps

Considering RMS value of V i.e. V=386.0 4 / $\sqrt{2}$ = 272.972 Volts Substituting these values in Eq.(1), one gets,

$2 = 272.972/ [(1)^2+(X'_L)^2]^{1/2}$ or $2 \times [(1)^2+(X'_L)^2]^{1/2} = 272.972$ On squaring both the side , one gets

$4 \times [(1)^2+(X'_L)^2]=(272.972)^2$

This would give us X'_L= 136.4823. Now from X'_L

$L'= 136.4823/2\pi f$, $L'=1.303$ H

X'_L values for higher harmonics would be obviously very high as compared to that for first harmonic corresponding to 16.66 cycles/sec frequency of current flowing through R' and X'_L branch. Therefore, corresponding currents flowing through R' and X'_L series arrangement is assumed to be zero. Thus R', X'_L branch itself works as a filter circuit for allowing only lowest

frequency component. Thus at the output of R' , X'_L branch the available voltage is 386.04 Volts RMS with 16.66 cycles/sec. Obviously, the system will need a step down transformer giving us potential of 230 Volts RMS value with 16.66 cycles/sec.

1. CONSTRUCTION DETAILS OF ASSEMBLY

The invention proposes evolution of a new type of cycloconvertor. This comprises of a circuit. The circuit is described in figure 3. Figure 3 comprises of components such as 1. Switches S1, S2, S3 and S4 2. Resistances R = 1 KΩ, resistance R' = 1 Ω and 3. Inductance L' = 1.303 H. In addition circuit also comprises of a single phase step down transformer [3] with turns ratio = 1.18. Above stated circuit components are connected as per the circuit diagram presented in figure 3. In figure 3 the available single phase voltage supply 230 volts rms value and 50 cycles/second is put across two parts of the complete circuit. One part is diode bridge invertor and the second part is coming straight across circuit component R, filter circuit branch R' - L' in series and primary of the single phase step down transformer. The diode D1, D2, D3 and D4 are so connected that the diode D2, switch S3, main resistance R and diode D3 invert the available supply during 10-20 milli-seconds from negative side to positive for resistance R = 1 KΩ. Whereas the diode D1, main resistance R = 1 KΩ, switch S4 and diode D4 invert the positive available supply during 40-50 milli-seconds to negative. Above is the description of fabricating the complete circuit for proposed cycloconvertor. The circuit is presented as per the usual conventions followed in electrical engineering for describing connections to be made for various circuit components.

2. PROPOSED FURTHER DEVELOPMENT

The proposed solution expects one additional system which will organize the closing and opening of involved all switches. To arrive at such closing and opening circuit will be a task in itself. The solution may lead to another adjunct patent.

3. ACKNOWLEDGEMENT

Authors are grateful to the management and administration of J D College of Engineering and Management, Nagpur for providing necessary infrastructure and support.

4. REFERENCES

[1] *Dr. P. S. Bhimbra, "Power Electronics" Khanna Publishers, first edition.*

[2] *William Keister "The Design of Switching Circuits", Bell Laboratories Series, second edition.*

[3] *B. L. Thareja, "A fundamental of Electrical Engineering and Electronics", S. Chand Publication, second edition*

[4] *Louis Albert Pipes, Lawrence R. Harvill, "Applied Mathematics for Engineers and Physicists" Dover Publication Inc., third edition.*