International Journal of Advance Research in Science and Engineering
Volume No.07, Special Issue No. (01), January 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

INDUSTRIAL POWER CONTROL BY INTEGRAL CYCLE SWITCHING WITHOUT GENERATING HARMONICS

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ABSTRACT

This paper deals with integral cycle switching, a method to remove whole cycle, cycles or portions of cycles of an AC signal. It is a well-known and old method of controlling AC power, especially across linear loads such as heaters used in electric furnace. However the concept of achieving the cycle stealing of voltage waveform by use of microcontroller can be very precise as per the program written in assembly / C language so that the actual time-average voltage or current experienced at the load is proportionately lower than the whole signal if applied to the load. Further this project can be enhanced by using feedback mechanism to automatically maintain desired output to the load by appropriate cycle stealing.

Keywords— Integral Switching Cycle Control, Phase Controlled Switching, Inter harmonics, Total Harmonic Distortion, Inrush current

I. INTRODUCTION

Most of the load needs variable or regulated ac power like welding, heating furnace requires variable ac supply. Ac voltage controllers are used to drive such loads. Usually it takes main supply as the inputs and provides variable ac to the load. Basically two types of ac-to-ac conversion are in use direct conversion and indirect conversion. In indirect ac-ac conversion involves an intermediate dc stage, called the dc link or dc bus and the converter are called dc link converter. During direct conversion the ac input waveforms are directly converted into the desired output waveforms. Phase Controlled Switching (PCS) is one of the methods of the direct conversion which is extensively used for adjustable ac-to-ac and ac-to-dc power conversion [1]. In case of heat controllers of resistive load (R), phase control circuits produce higher order inter harmonics and generate Radio Frequency Interference (RFI) and heavy inrush currents while switching on from cold. At large power levels, it requires bulky and expensive line filters to minimize RFI [2].

The most commonly used power electronic circuit for controlling the ac voltage is using two SCR's connected in anti-parallel between source and load. The control strategy depends upon the gate pulse given to the SCR's.

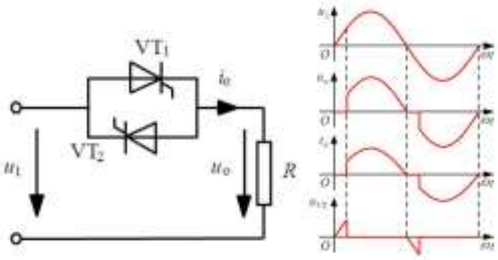


Fig. 1 (a) Switching arrangement of phase control circuit
(b) Waveforms of phase control circuit

Fig. 1 (a) shows the switching arrangement of phase control circuit. In the case of PCS, the rms value of output voltage is given by

$V0 = V\,[1/\pi\ \{(\pi - \alpha) - ½ \sin 2\alpha\}]^{1/2}$ … (1)

$P\,F = V_0/V$ … (2)

Where input supply voltage v(t) = Vm sinωt; Vm and V are maximum and rms values of the supply voltage and α is the switching angle of the circuit, as shown in fig. 1(b). The expression of Total Harmonic Distortion (THD) is given by

$$THD = \frac{\sqrt{\sum_{h=2}^{h\,max} V_h^2}}{V_1}[\%]$$

When α varies between 60 and 120, the supply voltage is close to its peak value (86.7% to 100%) and the corresponding voltage control range is from 44.2% to 89.7%. At the switching instant (ωt = α), the line current jumps from zero to almost its peak value Thus, di/dt is high over a wide range of control.

II. PRINCIPLE OF OPERATION

Integral cycle control is another method of direct conversion. It is also known as on-off control, zero switching or cycle selection. There are several applications in which mechanical time constant or thermal time constant is of order of several seconds for such application almost no variation in temperature is noticed if control is achieved by connecting the load to source for some on cycle and then disconnecting the load for some off cycles. So it consists of switching on supply to load for an integral number of cycles and then switching off the supply for a further number of integral cycles. It is repeated cyclically. The duty cycle is controlled for changing the output power basically it is an on-off control similar to the obtained through thermostatic switches except that here an integral number of cycles are passed. Due to zero voltage and zero current switching of thyristors, the harmonic generated by switching actions are reduced. Fig. 2 shows the output voltage waveform of ICC.

When the power is ON, during n cycle the temperature or speed increases exponentially from a minimum value and reaches a maximum at the end of n_{th} cycle. If n is the number of full cycles passed per M cycles of the source voltage then it is said to have a duty cycle of D= n/M. The difference between maximum of temperature and the minimum temperature is called the differential. Harmonic frequency present in ICC is lowest and low switching losses are produced so EMI and RFI problem will be less. Inrush current will also be less due to ZVS but smooth voltage control is not possible and frequency contained in ICC is variable.

Integral cycle control (ICC) is used for controlling power to an ac load by permitting few full cycles to power the load followed by off period. This is repeated cyclically. The duty cycle is controlled for changing the output power basically it is an on - off control similar to the obtained through thermostatic switches except that here an integral number of cycle are passed.

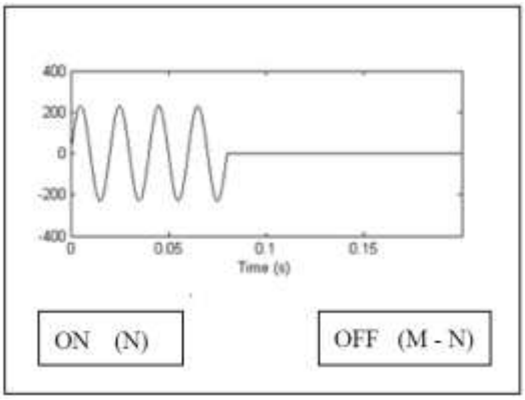


Fig. 2 Output waveform of ICC

If M is increased their differential increases and vice versa. Low value of M limit the variation in the value of N, as the smallest power available is

P min= (Vs2 * 1) / M * R when N =1 (4)

P max = Vs2 / R when N= M (5)

Control Ratio (CR) = P max / P min = M

The CR is independent of N but depends on M. ICC gives a much higher differential than phase control. Therefore it can be applied only to those processes where the process time constant is large, which keeps the differential low and higher value of M can be Chosen. Average power consumed by the load can be varied by Changing N keeping M fixed, Changing M keeping N fixed or changing both. Fig.3 shows the variation of output voltage for ICC with duty cycle=0.4

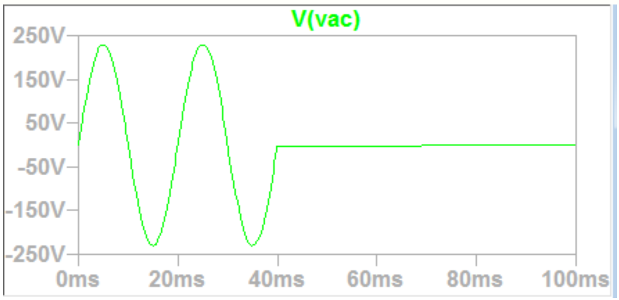


Fig. 3 Output waveform of ISCC with D = 0.4

III. PERFORMANCE CHARATERISTICS

The steady state converter performance measures can be put into four categories: Voltage Transfer Ratio (VTR), Current Reflection Ration (CRR), harmonic profile, component stresses

VTR: The forward voltage transfer ratio is defined as the ratio of the rms voltage output voltage to the rms input voltage.

CRR: The reflective characteristic gives the effect of load current on the current drawn by from the source. The CRR is defined as the ratio of the input current to the rms load current.

Harmonic Profile: The output voltage and source current wave form are non sinusoidal. The lowest undesired harmonic frequency in the voltage and input power factor are the measures used for the undesirable Fourier Component.

Component Stresses: Voltage and current in the switch may consist of high transient which may be considering higher than the normal operating voltage. These transients voltage dictate the selection of switching devices and hence determine the cost. The component stress is measured as the ratio of the peak Voltage (Current) to the rms value of the components

IV. SYSTEM DESIGN

Fig. 4 shows the proposed Block Diagram of ICC circuit, which involves the mainly Three sections.

1. Block Diagram:

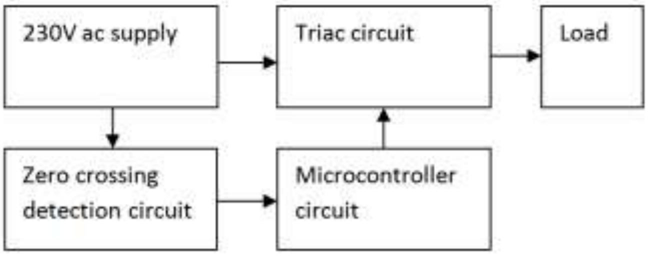


Fig. 4 Block diagram of ICC

1.1 . Zero crossing detection circuit:

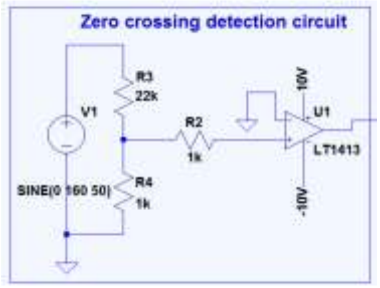


Fig. 5 Zero crossing detection circuit

A zero crossing detector or ZCD is a type of voltage comparator, used to detect a sine waveform transition from positive and negative, that coincides when the i/p crosses the zero voltage condition.It is a voltage comparator that changes the o/p between +Vsat &–Vsat when the i/p crosses zero reference voltage. In simple words, the comparator is a basic operational amplifier used to compare two voltages simultaneously and changes the o/p according to the comparison. For a reference voltage (Vref), when the input sine wave permits through zero voltage and goes in the direction of positive. The o/p voltage is driven into negative saturation. In the same way, when the Vin permits through zero and goes in the direction of the negative, the Vout is driven to positive saturation.

Fig.5 shows the Zero cross detection circuit simulated in LTSPICE in the proposed design. Fig.6 shows the Output of Zero crossing detection circuit in which V(n011) is the ac supply signal fed into the TRIAC circuit and V(n010) is the output of the comparator.

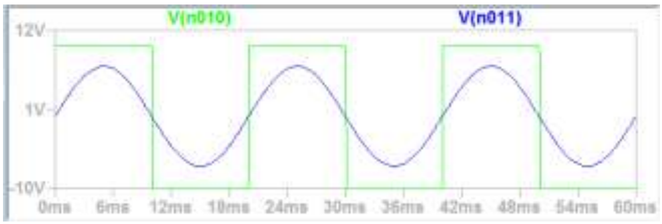


Fig. 6 Output of Zero crossing detection circuit

1.2. Microcontroller circuit:

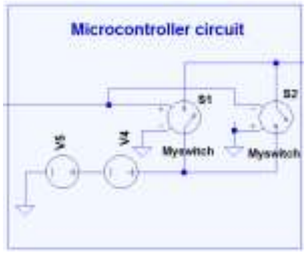


Fig. 7 Microcontroller circuit

The microcontroller detects a zero crossing event and outputs the required triggering pulse to the Triac circuit. There will be four switches corresponding to four different triggering pattern which in turn controls the output voltage to the load.

Fig.7 shows the Microcontroller circuit modeled in LTSPICE using switches S1 and S2.These switches are programmed in LTSPICE to generate the required triggering pattern of the TRIAC. Fig.8 shows its output waveform for 100% duty cycle

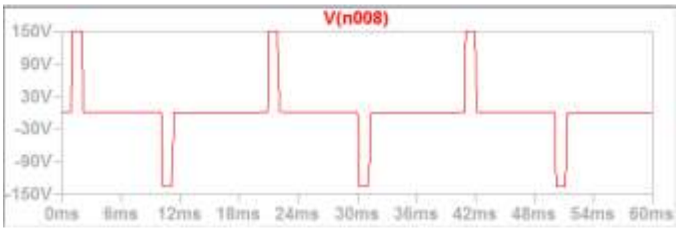


Fig. 8 Trigger pulses from Microcontroller circuit

1.3. TRIAC circuit:

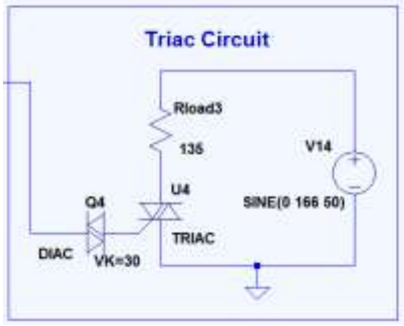


Fig. 9 Triac circuit

TRIAC has three terminals M1, M2 and gate. A TRIAC, lamp load and a supply voltage are connected in series. When supply is ON and the gate is triggered then the current flows through lamp. In negative half cycle the same thing repeats. Thus the lamp glows in both the cycles in a controlled manner depending upon the triggering pulses. If this is given to a motor instead of lamp the power is controlled resulting in speed control

Fig. 10 Output of integral cycle control (Triac circuit)

Fig.10 shows the output of the ICC circuit in which V(n008) is the triggering pulse and I(Rload3) is the output load current waveform.

V. SIMULATION

A complete Simulation of Phase Controlled Switching (PCS) and Integral cycle control (ICC) has been carried out using LTSPICE and the results are discussed for various duty cycles as shown in Figure.

Fig 11 shows the simulation circuit of Phase Controlled Switching (PCS) . Fig 11(a) and Fig 11(b) shows the output of PCS at different firing angle α.

Fig 12(a) shows the simulation results for ICC with D=0.3. Fig 12(b) shows the simulation results for ICC with D=0.8

VI. RESULTS

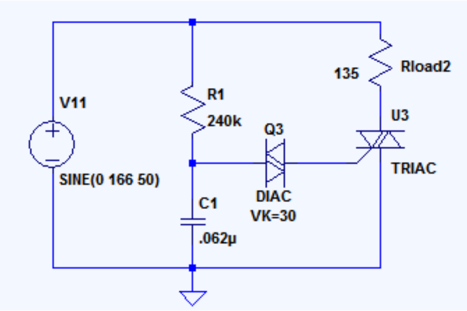


Fig. 11 Phase Controlled Switching (PCS) circuit

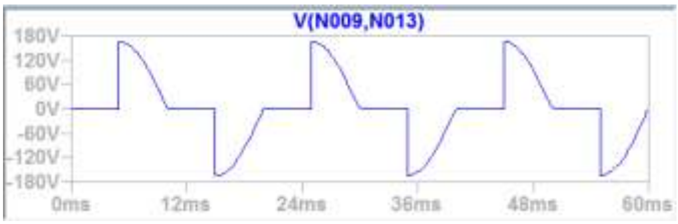


Fig. 11(a) Output voltage of (PCS) circuit at α=90 deg

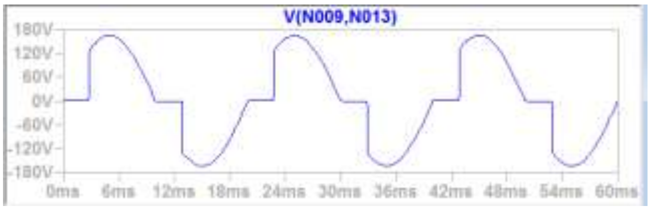


Fig. 11(b) Output voltage of (PCS) circuit at α=30 deg

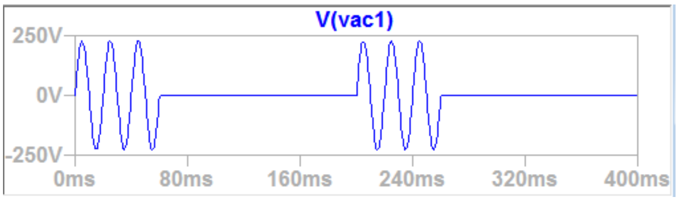


Fig. 12(a) Output Load Waveform of ICC D = 0.3

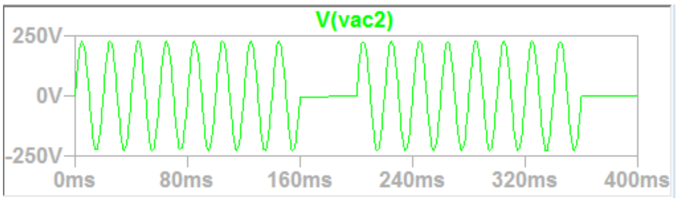
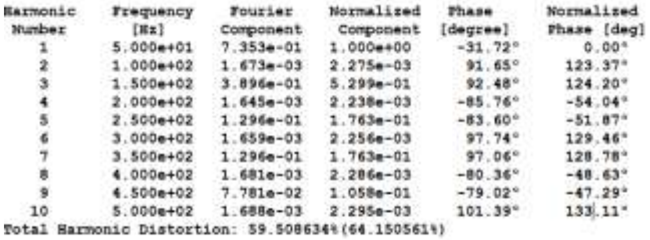


Fig. 12(b) Output Load Waveform of ICC D = 0.8

Fig 13(a) and Fig 13(b) shows the simulation result of Total harmonic distortion obtained from LTSPICE for PCS and ICC respectively. In PCS it is found that THD=59.5% and in ICC THD=4.15%.



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Harmonic   Frequency   Fourier     Normalized   Phase      Normalized
 Number      [Hz]      Component   Component   [degree]   Phase [deg]
    1      5.000e+01   7.353e-01   1.000e+00    -31.72°       0.00°
    2      1.000e+02   1.673e-03   2.275e-03     91.65°     123.37°
    3      1.500e+02   3.896e-01   5.299e-01     92.48°     124.20°
    4      2.000e+02   1.645e-03   2.238e-03    -85.76°     -54.04°
    5      2.500e+02   1.296e-01   1.763e-01    -83.60°     -51.87°
    6      3.000e+02   1.659e-03   2.256e-03     97.74°     129.46°
    7      3.500e+02   1.296e-01   1.763e-01     97.06°     128.78°
    8      4.000e+02   1.681e-03   2.286e-03    -80.36°     -48.63°
    9      4.500e+02   7.781e-02   1.058e-01    -79.02°     -47.29°
   10      5.000e+02   1.688e-03   2.295e-03    101.39°     133.11°
Total Harmonic Distortion: 59.508634%(64.150561%)
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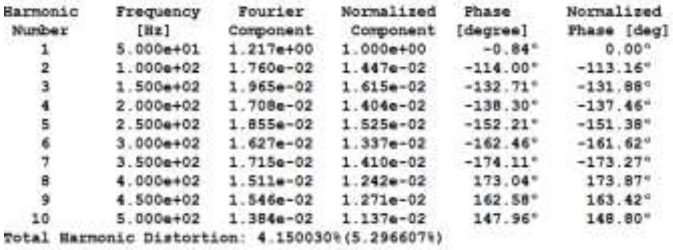
Fig. 13(a) Total Harmonic distortion of PCS



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Harmonic   Frequency   Fourier     Normalized   Phase      Normalized
 Number      [Hz]      Component   Component   [degree]   Phase [deg]
    1      5.000e+01   1.217e+00   1.000e+00     -0.84°       0.00°
    2      1.000e+02   1.760e-02   1.447e-02   -114.00°    -113.16°
    3      1.500e+02   1.965e-02   1.615e-02   -132.71°    -131.88°
    4      2.000e+02   1.708e-02   1.404e-02   -138.30°    -137.46°
    5      2.500e+02   1.855e-02   1.525e-02   -152.21°    -151.38°
    6      3.000e+02   1.627e-02   1.337e-02   -162.46°    -161.62°
    7      3.500e+02   1.715e-02   1.410e-02   -174.11°    -173.27°
    8      4.000e+02   1.511e-02   1.242e-02    173.04°     173.87°
    9      4.500e+02   1.546e-02   1.271e-02    162.58°     163.42°
   10      5.000e+02   1.384e-02   1.137e-02    147.96°     148.80°
Total Harmonic Distortion: 4.150030%(5.296607%)
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Fig. 13(b) Total Harmonic distortion of ICC

Hence Integral cycle control (ICC) is more better in terms of THD observed compared to that of Phase Controlled Switching (PCS)

VII. CONCLUSION

The two main control strategies of AC voltage controller used to control the output voltage is discussed in this paper. In Integral cycle control (ICC) even though the %THD is less wide range of voltage control is not possible where as in phase angle control smooth voltage variation can be achieved but %THD is high. So to eliminate above drawbacks the integral switching cycle control(ICC) technique can be used in which by setting duty cycle constant and varying firing angle can lead to get both smooth voltage variation and reduced %THD. For the same power output 125% reduction in THD is observed. The switching of the switches has been done at zero voltage and current so voltage stresses is reduced.

This paper also discuss the simulation study of AC voltage controller control strategy using LTSPICE. It is concluded that ICC is more efficient than PCS in terms of percentage THD.

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