

## Ac/Ac Converter for Single Phase Induction Motor with Dc-Modulation

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**Abstract:** This paper explain the design and calculation of AC/AC converter for single phase induction motor (split phase motor) drive with DC - modulation. In conventional AC/AC converter, the output frequency and total harmonic distortion (THD) are their limitation factors. In order to overcome the above limitations, the AC/AC converters which is based on DC modulation gives improved power factor (p.f.) and the higher power transmission efficiency and hence can be used for single phase induction motor.. Simulation results verify the design of DC-modulated single stage buck type AC/AC converter for single phase induction motor.

**Keywords:** DC-modulation, Power factor correction, total harmonic distortion (THD), single phase induction motor.

### I. Introduction

Ordinary strategies for AC/AC converter having a few disadvantages like – output voltage is by and large lower than the input side voltage, total harmonic distortion (THD) is poor and output frequency does match with the input frequency by utilizing traditional voltage regulation method, cycloconverters and matrix converters. The novel DC regulated AC/AC converters are commonly used to overcome the above disadvantages.

A classic single stage AC/AC converter with voltage regulation technique and respective waveforms are given in Fig. 1 Consider a load as resistive [1-4], the input supply voltage is

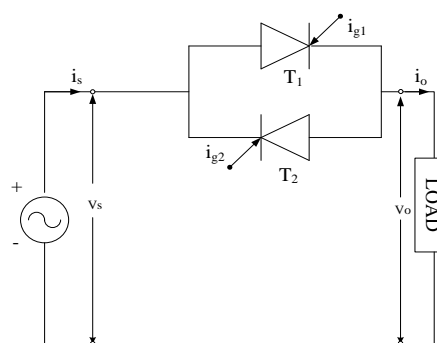
$$v_s(t) = \sqrt{2}V_s \sin \omega t \quad (1)$$

Where  $V_s$  is the rms value,  $\omega$  is the input radian frequency,  $\omega = 2\pi f = 100\pi$  ( $f = 50\text{Hz}$ ). The power factor is given by [6].

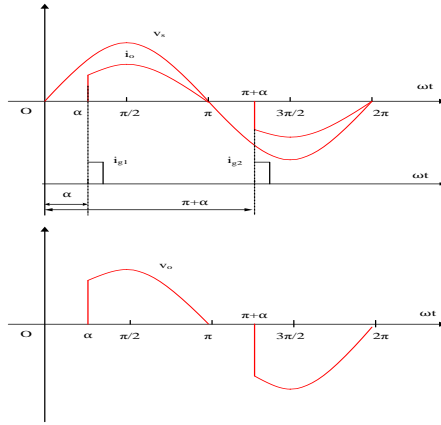
$$PF = \frac{DPF}{\sqrt{1 + THD^2}} \quad (2)$$

Where the displacement power factor is  $DPF = \cos\Phi_1$ , the phase angle of the fundamental harmonic component is  $\Phi_1$ . It means that for firing angle  $\alpha$  is  $45^\circ$  (i.e.  $\Phi_1$  is  $45^\circ$ ), the typical values are that  $DPF = \cos 45^\circ = 0.707$  and THD is 0.2831 (or 28.31%). Therefore,  $PF = 0.680$  and considered as a poor PF.

The DC/DC conversion topologies are generally having the advantage of fast response time and high efficiency. By applying DC-modulation power factor correction AC/AC conversion can lead to high PF. Consider a DC-modulated single-stage Buck-type AC/AC converter is given in Fig. 2 Assume the supply voltage is 240 Vrms. The two bidirectional switches required as SM and SS for the DC-modulation operation. [5-10]



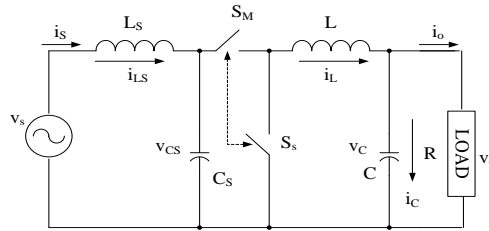
Circuit diagram



(b) Waveforms

**Fig. 1** Conventional single stage AC/AC converter.

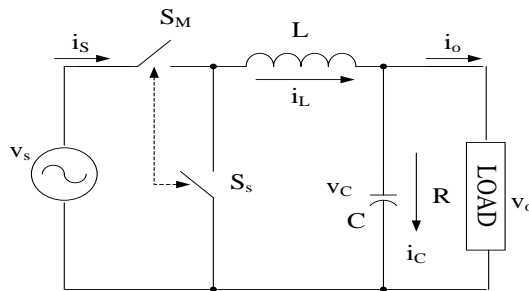
The switching frequency of DC-modulation  $f_m$  is generally high,  $f_m = 20$  kHz and this leads to input power supply voltage as semi static DC voltage (positive or negative) in a DC-modulation period of  $T_m = 1/f_m$  (50  $\mu$ s). During AC/AC conversion the input side low-pass filter  $L_S - C_S$  is required as the Buck converter input supply current is pulse train.



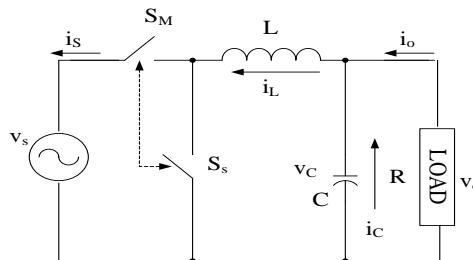
**Fig. 2** Buck type DC-modulated AC/AC converter.

## II. Dc-Modulated Single – Stage Buck – Type Ac/AC Converter

In organize to consider the operation of AC/AC converter both positive and negative half-cycle of the input supply voltage considered for procedure. In the positive half-cycle of input supply voltage.



Equivalent circuit diagram-AC Positive half-cycle.



Equivalent circuit diagram-AC Negative half-cycle.

**Fig. 3** Buck type DC-modulated AC/AC converter.

The equivalent circuit is given in Fig. 3 (a) The output voltage is calculated by

$$v_o = kv_s = k\sqrt{2}V_s \sin \omega t \quad 0 \leq \omega t < \pi \quad (3)$$

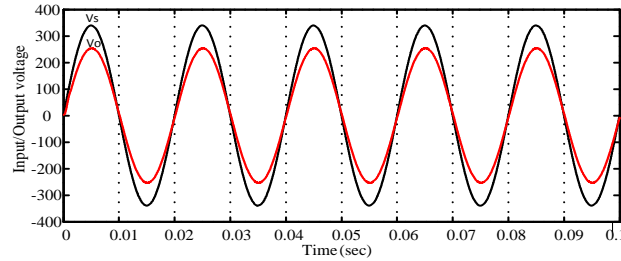
In the negative half-cycle of input supply voltage. The equivalent circuit is given in Fig 3 (b). The output voltage is calculate by

$$v_0 = -k|v_s| = k\sqrt{2}V_s \sin \omega t \quad \pi \leq \omega t < 2\pi \quad (4)$$

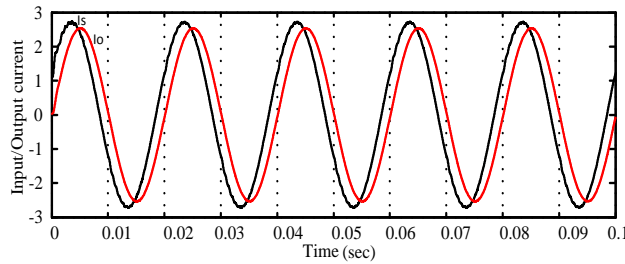
Combine two state operations gives the whole-cycle operation.

$$v_0 = kv_s = k\sqrt{2}V_s \sin \omega t \quad (5)$$

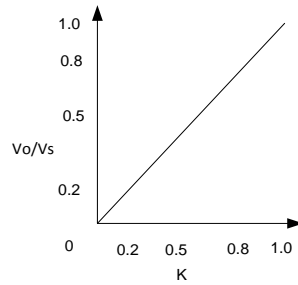
The input/output voltage whole cycle waveform is given in Fig. 4 and input/output current waveform is given in Fig. 5 Voltage transfer gain versus duty cycle  $k = 0.75$  is given in Fig. 6 For different duty cycle the output voltage/current/power will be with high PF and high efficiency.



**Fig. 4** Input/ Output voltage waveform of AC/AC converter with DC-modulation



**Fig. 5** Input/Output current waveform of AC/AC converter with DC-modulation.



**Fig. 6** The voltage transfer gain ( $V_o/V_s$ ) versus duty cycle ( $K$ ).

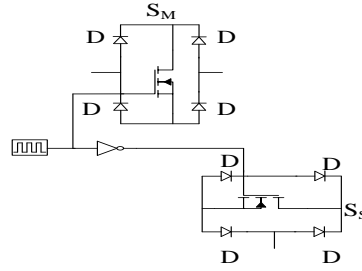
### III. Bidirectional Exclusive Switches $S_m$ - $S_s$

The AC/AC conversion with DC-modulation method requires bidirectional switches. The switch can be MOSFETs and IGBTs. The technical features of bidirectional switches  $S_m$  –  $S_s$  are:

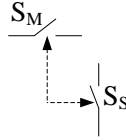
The master switch  $S_m$  conduct the forwardly flow current in the positive input voltage and also conduct the reversely flow current in the negative input voltage. The master switch always prohibited by a PWM pulse-train.

The slave switch  $S_s$  switches on when master switch  $S_m$  switched-off exclusively. It provides free-wheeling action.

The bidirectional select switches  $S_m$ - $S_s$  circuit configuration is given in Fig. 7 It prescribed by a PWM pulse-train having adjustable frequency  $f_m$  and pulse-width. The time period  $T_m = 1/f_m$  and the conduction duty cycle calculated as  $k = (\text{pulse width})/T_m$ .



A circuit of bidirectional exclusive switches SM-SS.



A symbol of bidirectional exclusive switches SM-SS.

**Fig. 7** DC-modulated bidirectional switches SM-SS operation.

#### IV. Mathematical Modeling Of Dc/Dc Converters.

According to Luo and Ye [11-12], the points for the design of DC/DC converter are given as follows:  
The input pumping energy is PE.

$$PE = \int_0^{T_m} V_s i_s(t) dt = V_s \int_0^{T_m} i_s(t) dt = V_s I_s T_m \quad (6)$$

Where the average input supply current

$$I_s = \frac{1}{T_m} \int_0^{T_m} i_s(t) dt$$

The inductor stored energy is

$$W_L = \frac{1}{2} L I_L^2 \quad (7)$$

The capacitor stored energy is

$$W_C = \frac{1}{2} C V_C^2 \quad (8)$$

Therefore, the total stored energy (SE) in a DC/DC converter for  $n_L$  inductors and  $n_C$  capacitors is

$$SE = \sum_{j=1}^{n_L} W_{Lj} + \sum_{j=1}^{n_C} W_{Cj} \quad (9)$$

The energy factor EF is,

$$EF = \frac{SE}{PE} = \frac{SE}{V_s I_s T_m} = \frac{\sum_{j=1}^{n_L} W_{Lj} + \sum_{j=1}^{n_C} W_{Cj}}{V_s I_s T_m} \quad (10)$$

The capacitor/inductor stored energy (CIR) is define as,

$$CIR = \sum_{j=1}^{n_C} W_{Cj} / \sum_{j=1}^{n_L} W_{Lj} \quad (11)$$

The time constant  $\tau$ :

$$\tau = \frac{2T_m \times EF}{1 + CIR} \left( 1 + CIR \frac{1 - \eta}{\eta} \right) \quad (12)$$

The damping time constant

$$\tau_d = \frac{2T_m \times EF}{1 + CIR} \left( \frac{CIR}{\eta + CIR(1 - \eta)} \right) \quad \text{With } \tau_d = \zeta \tau \quad (13)$$

A DC/DC converter has the transfer function

$$G(s) = \frac{M}{1 + s\tau + s^2\tau\tau_d} = \frac{M}{1 + s\tau + s^2\tau^2\xi} \quad (14)$$

Where M is the voltage transfer gain and  $M = k$  for a Buck converter. The above model described with considering Buck converter having  $L = 10$  mH,  $C = 3$   $\mu$ F, the load  $R = 100$   $\Omega$ , input voltage and current are  $V_S$  and  $I_S$ , output voltage and current are  $V_o$  and  $I_o$ , no power losses, i.e.  $\eta = 1$ . The following obtain data as given by:

$$v_o = kv_S \quad i_S = ki_o$$

$$v_o = Ri_o \quad P_{in} = v_S i_S = v_o i_o = P_o \quad \text{With } \eta = 1$$

$$PE = \int_0^{T_m} V_S i_S(t) dt = V_S \int_0^{T_m} i_S(t) dt = V_S I_S T_m$$

$$W_L = \frac{1}{2} LI_o^2$$

$$W_C = \frac{1}{2} CV_o^2$$

$$SE = \frac{1}{2} LI_o^2 + \frac{1}{2} CV_o^2$$

$$EF = \frac{SE}{PE} = \frac{L/R + CR}{2T_m}$$

$$\tau = \frac{2T_m \times EF}{1 + CIR} = \frac{L/R + RC}{1 + CIR} = 300.75 \mu s$$

$$\tau_d = \frac{2T_m \times EF}{1 + \frac{1}{CIR}} = 99.24 \mu s$$

Hence the transfer function is given as

$$G(s) = \frac{M}{1 + s\tau + 2s^2\tau} \quad (15)$$

The transfer function in equation (12) having two folded poles so the step-response will faster in time domain.

$$g(t) = M[1 - e^{-\frac{t}{2\tau_d}} (\cos \omega t - \frac{1}{\sqrt{4\tau_d/\tau - 1}} \sin \omega t)] \quad (16)$$

The power supply time period  $T = 1/f = 20$ ms and the settling time period from one steady state to another one is  $3\tau = 0.902$ ms which is much lesser than the supply time period.

## V. Single Phase Induction Motor

A single phase induction motor having limitations of poor starting torque. To make the motor self start some arrangements are required so that motor can produce starting torque. The methods for self starting of single phase induction motor is providing an extra winding such as auxiliary winding on the stator side in addition with main winding and motor start as a two phase machine. The main winding and auxiliary winding in stator are phase displaced by  $90^\circ$ . The current in main winding and auxiliary winding are phase shift from each other, result is stator field generate the starting torque and motor behave as a balanced two phase motor.

In split phase induction motor main winding generally having high reactance but low resistance and auxiliary winding has low reactance but high resistance. The auxiliary winding having high resistance to low reactance ratio obtained by using reasonable wire because the auxiliary winding use in the circuit only during starting period. In auxiliary winding the switch is connected in series and disconnected at about 75% of synchronous speed. Split phase induction motor has low to moderate starting torque which depends on main and auxiliary winding current and phase angle between them. [13]

## VI. Simulation Results And Analysis

The single phase induction motor (split phase) connection with AC supply consider for simulation as shown in Fig. 8

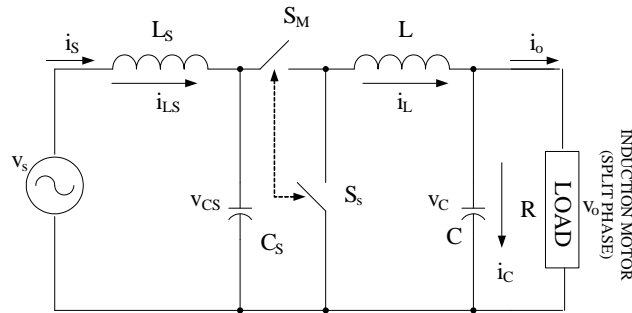


Fig. 8 Simulation circuit of induction motor with AC supply.

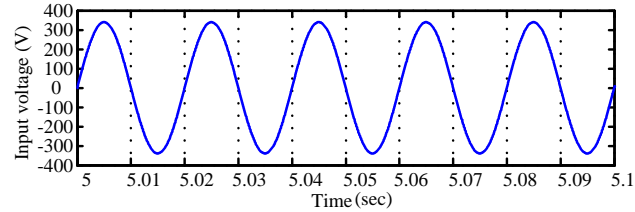


Fig. 9 Input voltage waveform of AC/AC converter with DC-modulation.

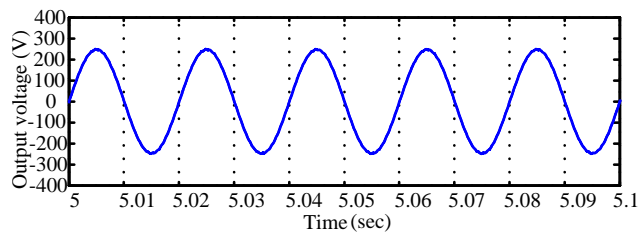


Fig.10 Output voltage waveform of AC/AC converter with DC-modulation.

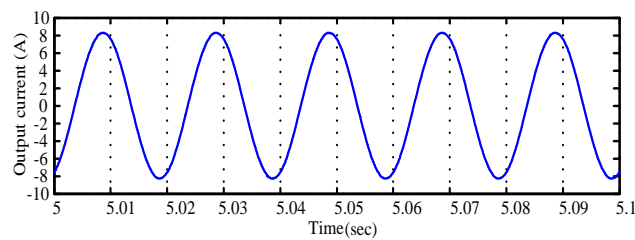


Fig. 11 Output current waveform of AC/AC converter with DC-modulation

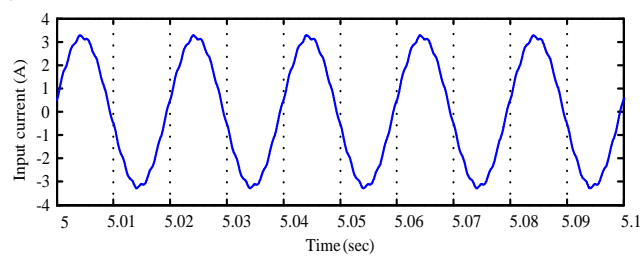


Fig. 12 Input current waveform of AC/AC converter with DC-modulation.

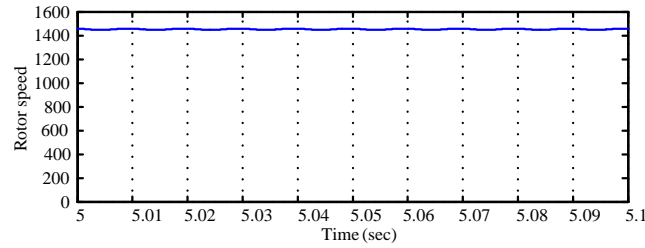


Fig. 13 Single phase induction machine speed.

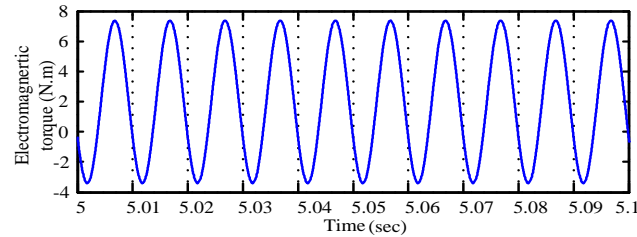


Fig. 14 Single phase induction machine Electromagnetic torque.

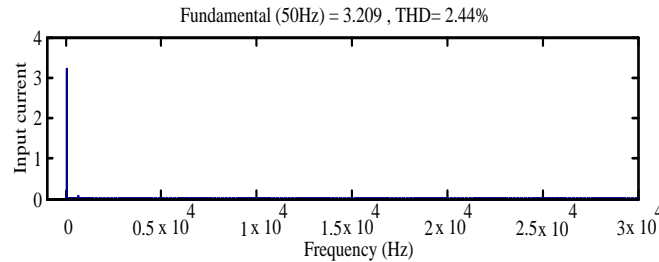


Fig. 15 Harmonic analysis of input current.

The Buck-type DC-modulated AC/AC converter for single phase induction motor drive having following components selected for simulation:

DC-modulated AC/AC converter components:  $L_s = 1\text{mH}$ ,  $C_s = 60\mu\text{F}$ ,  $L = 10\text{mH}$ ,  $C = 3\mu\text{F}$  and the duty cycle is selected as  $k = 0.75$ . Single phase Induction machine parameters: 1hp, 240V, 50Hz.

The simulation result of AC/AC converter input voltage  $V_s = 240\text{ Vrms}$  is given in Fig. 9 and output voltage  $V_o = 180\text{ Vrms}$  is given in Fig. 10. The input supply voltage and output voltage having frequency  $f = 50\text{Hz}$ . and there is not any phase delay between output voltage and input voltage. The simulation result of AC/AC converter output current  $I_o = 6.016\text{ A}$  is given in Fig. 11. The input current  $I_s = 2.305\text{ A}$  of AC/AC converter is given in Fig. 12. And input current leading with input voltage thus the Induction motor drive with DC-modulated AC/AC converter is operating at leading power factor. The induction motor speed is found to be 1458 rpm as given in Fig. 13. And the torque in split phase operation mode is given in Fig. 14. The load torque is 2 N.m. The torque ripple amplitude is 7.4 N.m.

The simulation results with consideration of power losses in the converter. The input power  $P_{in} = 536.5\text{ W}$  and the converter output power  $P_o = 450.9\text{ W}$ . The power transfer efficiency  $\eta = P_o/P_{in} = 84.04\%$ . And the simulation results shows that the final PF = 0.9851. If no power losses in an ideal condition converter input power  $P_{in} = 459.6\text{ W}$  and the converter output power  $P_o = 451.3\text{ W}$ . The power transfer efficiency  $\eta = P_o/P_{in} = 98.19\%$ . And the simulation results shows that the final PF = 0.9835. The spectrum of input current obtained with little distortion at from the harmonic component IM at 20 kHz and much far away from a fundamental component IS at 50 Hz. The parameters obtained as THD = 2.44%, DPF = 0.9854 and the final PF = 0.9851 is given in Fig. 15.

## VII. Conclusion.

The DC-modulated power factor correction AC/AC converter can be use to drive single phase induction motor. It also overcomes the disadvantage of traditional AC/AC converters as high total harmonic distortion, poor power factor and poor power transfer efficiency. The DC-modulate AC/AC converter

successfully improved the power factor up to  $PF=0.9851$  and the power transfer efficiency up to 84.04%. The simulation results verify the design and calculation of DC-modulated single stage buck type AC/AC converter for single phase induction motor drive.

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