A FULLY CONTROLLED PWM DIGITAL INVERTER

A.A. Heggo*

ABSTRACT

In recent years digital inverters have been widely used. Regarding the advantages of using an ac motor instead of a dc motor, the digital inverter technology is applied. One of the most and important applications is for traction systems. Dc bus-bar is available by the ordinary method of rectification which is considered as an input to the inverter. Then the inverter output should be three-phase ac voltage. Micro computer enables to vary the amplitude and duration of the dc voltage using the PWM (pulse-width modulation) to control the input voltage which produces a variable voltage variable frequency (VVVf). The system mathematical model, non-linear model and linear model around operating point will be presented. The simulation programme and experimental results have been obtained and commented.

KEY WORDS

Digital Control, VVVf (variable voltage variable frequency), deadbeat control.

NOMENCLATURE

- W = pulsation frequency
- V = average voltage
- V_m = maximum ac voltage
- V_{dc} = actual output dc voltage
- V_{dco} = average output dc voltage
- V_{dq} = dc voltage component in quadrature axis
- I = average current

* National Authority for Tunnels

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I_{dc} = dc output current
I_{dq} = dc current component in quadrature axis
E = harmonic voltage rms value
P_{out} = output dc power
Θ = displacement angle
α = firing angle
n = higher harmonic degree
= higher harmonic phase angle
u = commutation overlap angle
V_i = input dc voltage
V_o = output ac voltage
A = amplifier gain
V_u = ultimate value of dc voltage
V_L = lower value of dc voltage
R = resistance of input filter
C, L = capacitance, inductance of L - C filter
T_s = switching interval

1. INTRODUCTION

The full control of speed of a three-phase induction motor can be achieved by using this new prediction scheme. The proposed prediction mainly consists of an ac network, high tension, step down transformer, medium tension and auto transformer with metal rectification to get a high current input dc power supply. The main advantages include unity power factor, high quality sinusoidal input current resulting in reduced harmonics, bi-directional power flow and control over the dc voltage magnitude [1].

This new technology of getting a variable voltage, variable frequency enables a wide range of speed control applications [2]. One of the most and efficient applications is ac traction instead of dc traction. The digital inverter is more convenient and reliable for converting the dc voltage to ac voltage. The advantages of a digital inverter is not only to get smoothing variation in amplitude of output voltage but also to get some smoothing for the output frequency [3]. Consequently the fully controlled speed of a three-phase squirrel cage induction motor can be achieved.

2. SYSTEM SYNTHESIS

The system under study is shown in Figure 1. The input alternating voltages are forced to be in phase with the alternating current. The output power (ac) depends upon the input power (ac) and the stored power (dc), boost power in induction coil (L). The current regulator function is to make the linear relation between input and output, in other words to avoid the hysteresis phenomena, this means to get a fast dynamic response and good steady state performance. The proportional-integral controller function is to eliminate steady-state error. Consequently there is in-phase between input and output voltages.

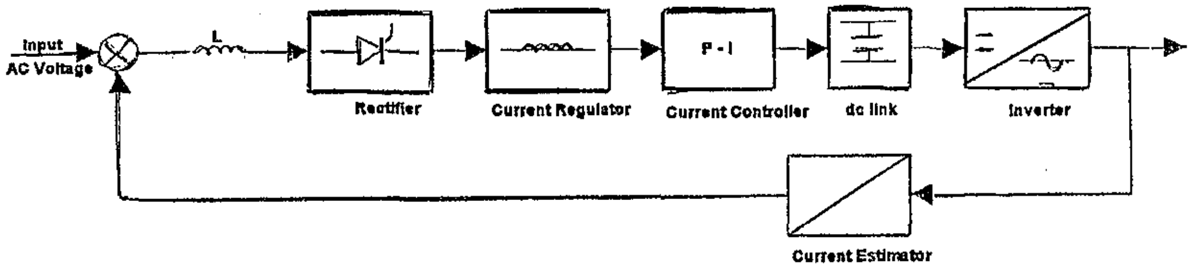

Fig. 1 - System Description

But in general there is a certain delay between input samples and control action which is composed of:

- Computation delay
- Control lag inherent in deadbeat control strategy [4][5].

This delay comprises two components:

. 1st - Control Computation time delay which is T_s
. 2nd - deadbeat control action takes T_s as shown in Fig. 2

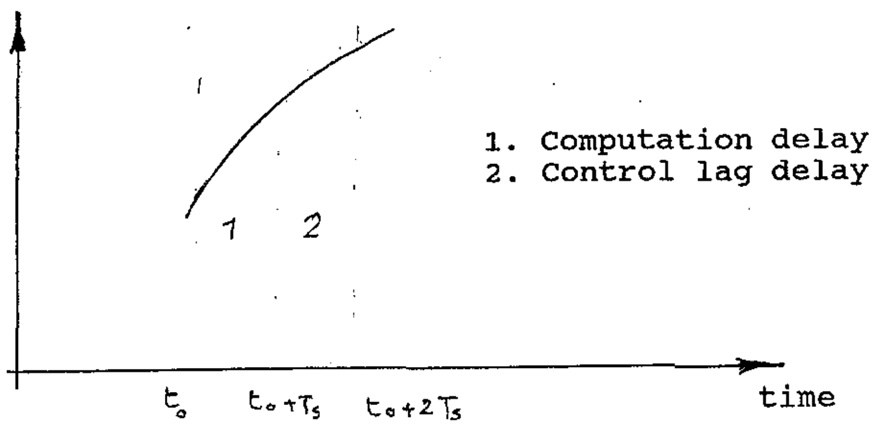

Fig. 2 - Delay in the deadbeat Control Strategy

To reduce the error introduced by this delay, the voltage reference which is based on the present measurements of system variables should be predicted two switching intervals, $2T_s$ in the future. In case of balanced sinusoidal supply condition and fixed steady load, this amounts to the addition of fixed load lead of $4\pi T_s$ to the voltage reference [6].

3. THE MATHEMATICAL MODELLING

The voltage and current equations in direct axis, quadrature axis are:

$$V_{dq} = V_d + jV_q \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$I_{dq} = I_d + jI_q \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The desired current reference that:

- results from input\output balance
- produce unity input power factor
- results in input sinusoidal currents

$$I_{dref}\ (t) = \frac{2}{3}\ \frac{V_d\ (t)}{V_d^2\ (t) + V_q^2\ (t)}\ P_{cut}\ (t) \quad \ldots\ldots\ldots \quad (3)$$

$$I_{qref}\ (t) = \frac{2}{3}\ \frac{V_q\ (t)}{V_d^2\ (t) + V_q^2\ (t)}\ P_{cut} \quad \ldots\ldots\ldots\ldots \quad (4)$$

where

$$P_{cut} = V_{dc}I_{dc} + K_1\ (V_{dcref} - V_{dc}) + K_2\ \ (V_{dcref} - V_{dc})\,dt \quad (5)$$

This represents the power output requirement at instant (t) and is computed as the combination of load feed forward and P-1 controller of dc bus voltage error.

The delay period is to be passed before the control action is applied. This could cause the regulator to become oscillatory. This action may be done at low frequency switching. So the integral term corrects this problem. The relation between instant voltage and control voltage in rectifier side is as follows:

$$V'_{qdref}(t) = V_{qd}(t) - L\frac{(I_{qdref} + 2T_s) - I_{qd}(t + T_s)}{T_s} \quad \ldots\ldots \quad (6)$$

where

$$I'_{qd}(t+t_s) = I_{qd}(t) + \{V_{qd}(t) - V_{qd}(t-T_s)\} \frac{T_s}{L} \;\ldots\ldots\; (7)$$

Equation (7) is calculated from instantaneous input voltage and control voltage V'_{qd} supposing that V_{dc} is constant.

Also the dc output voltage from ac input voltage is:

$$V_{dc} = V_{dco} + \Sigma\sqrt{2}\, E \sin(\Theta + \alpha) \;\ldots\ldots\ldots\ldots\ldots\ldots\; (8)$$

and

$$E = \frac{V_{dco}}{\sqrt{2}\,(n^2 - 1)} \sqrt{u} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (9)$$

$$u = 2\cos^2\alpha + (n^2+1)\sin^2\alpha + (n^2-1)\sin^2(\alpha+u) + \cos nu[2\cos\alpha \cos(\alpha+u) + 2n^2\sin\alpha \sin(\alpha+u)] \; (10)$$

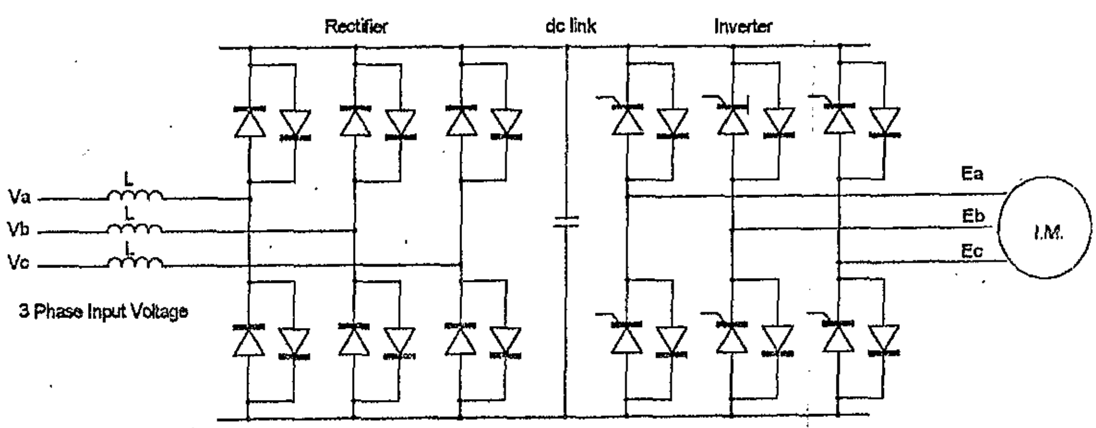

Fig. 3 - Schematic diagram connection for ac/dc converter

Equations (8) and (9) represent the output dc voltage and harmonic voltage.

In the system under study Fig. (3) - 12 pulse mode of operation the harmonic voltage has not to exceed certain permissible limits. On the other hand the equations of dc-ac side will be:

$$V_i = \frac{T_2}{T} \frac{VL + Vu}{2} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (11)$$

$$V_o = \frac{T_1}{T} \frac{VL + Vu}{2} \quad (12)$$

$$V_o = AV_i \quad (13)$$

where

$$T_1 = Rc \frac{Vu - VL}{V_o} \quad (14)$$

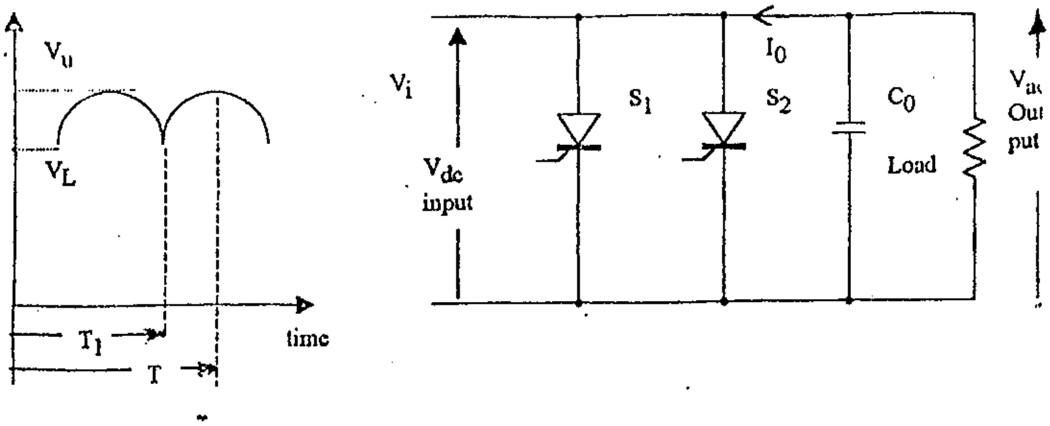

Fig. (4) Full wave 3-phase inverter

$$T_2 = Rc \frac{(Vu - VL)}{V_o} \frac{V_i}{V_o} \quad (15)$$

$$T = \frac{Rc}{2} \frac{Vu^2 - VL^2}{Vo^2} \quad (16)$$

$$A = \frac{Vu + VL}{2V_i} - 1 \quad (17)$$

The equation (13) represents the relation between input dc voltages and output ac voltage.

4. DESIGN CONSIDERATION

As shown in Fig. (4) the voltage reversal in both sides dc or ac can be made. This gives the circuit the capability of two quadrant operation. The four quadrant operation can be achieved by providing current reversible paths to the circuit. Generally, the upper limit of input voltage Vu is larger than the source voltage. But the lower limit of input voltage is kept as small as possible to maximise the energy transfer by minimising the energy returned from the output filter.

5. SIMULATION RESULTS

A computer model program was prepared to study the complete behaviour of the converter. This programme is convenient for small and large signal transients. During the start-out there is a maximum limit in the increasing of voltage gain, achievable for each cycle. The results obtained are shown in Figures (5), (6) and (7).

The electrical data is

* ac side 1

  - number of phases = 3
  - input voltage = 380 V
  - input frequency = 50 Hz
  - Type of rectifier = 12 - pulse mode

* dc side

  - rated voltage = (500 - 900V)
  - average voltage value = 750V
  - rated current = 4000A

* ac side 2

- number of induction motors/car = 4 motors
- rated voltage = 550V
- rated power = 115Kw
- rated current = (129 - 156)A/inverter up to +17%
- frequency = up 70Hz
- slip frequency = 1.7

6. CONCLUSION

The rectifier-inverter set is presented and discussed in this paper. The mathematical model is derived. The simulation results are introduced and commented. This method ac- dc - ac allows to use squirrel cage induction motor. Control constraints imposed the output ac voltage is also discussed. The experimental results almost coincide with the simulation results.

7. REFERENCES

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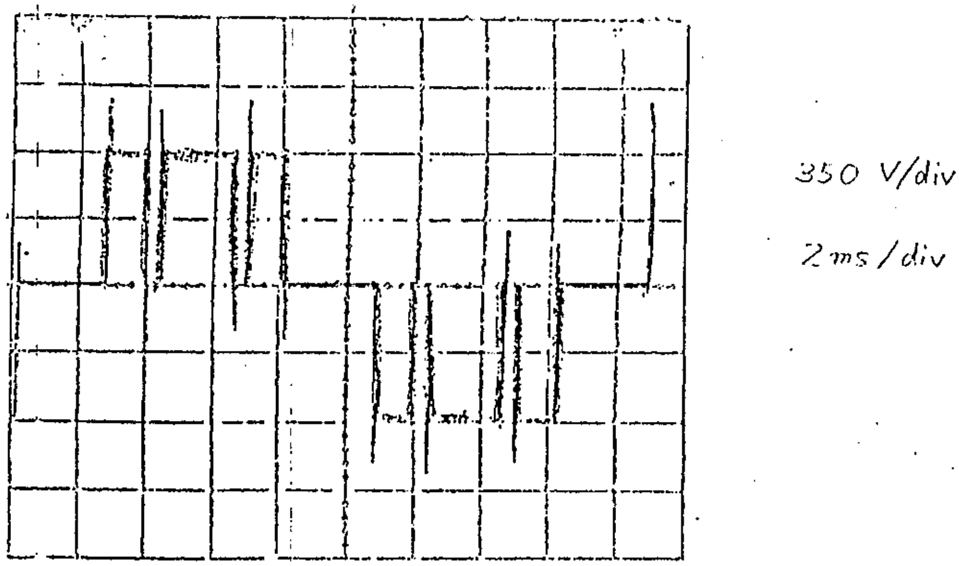
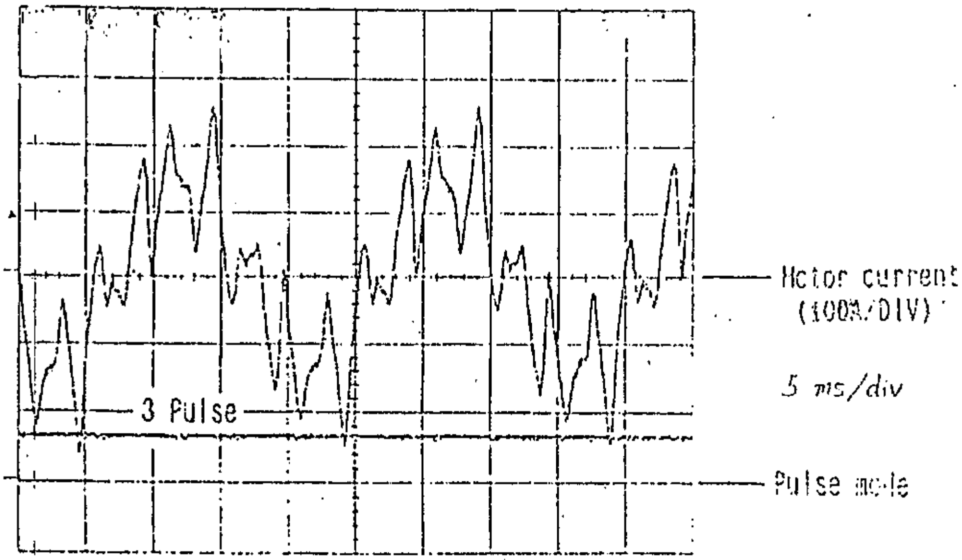
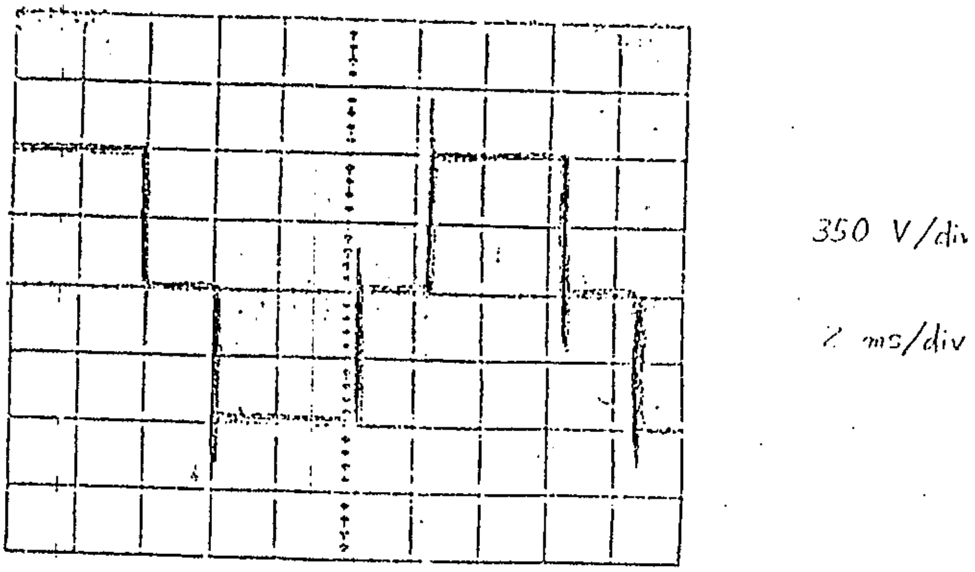


(5–a) VOLTAGE WAVEFORM

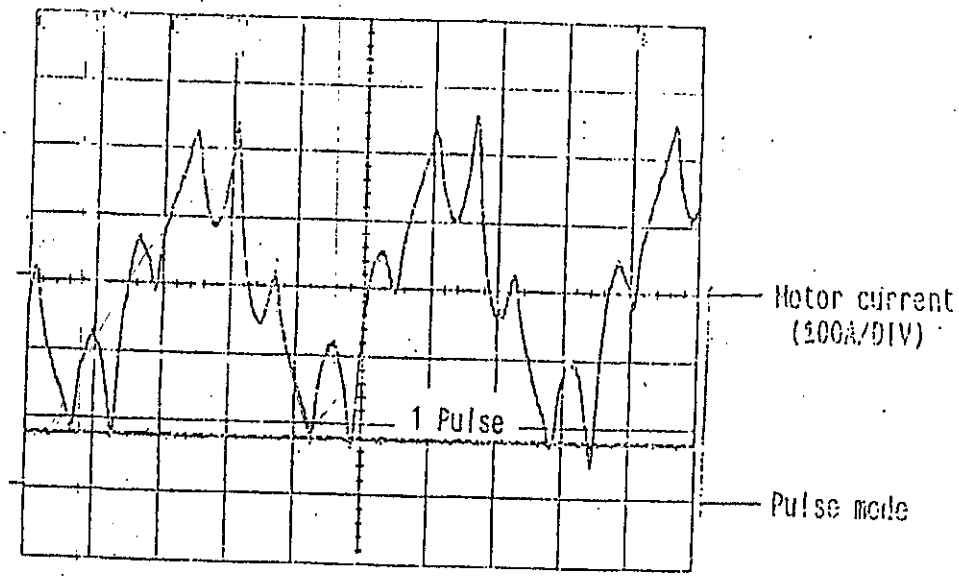


(5–b) CURRENT WAVEFORM

Fig.5 The voltage and current waveforms under the "3 Pulse Modulation Mode".

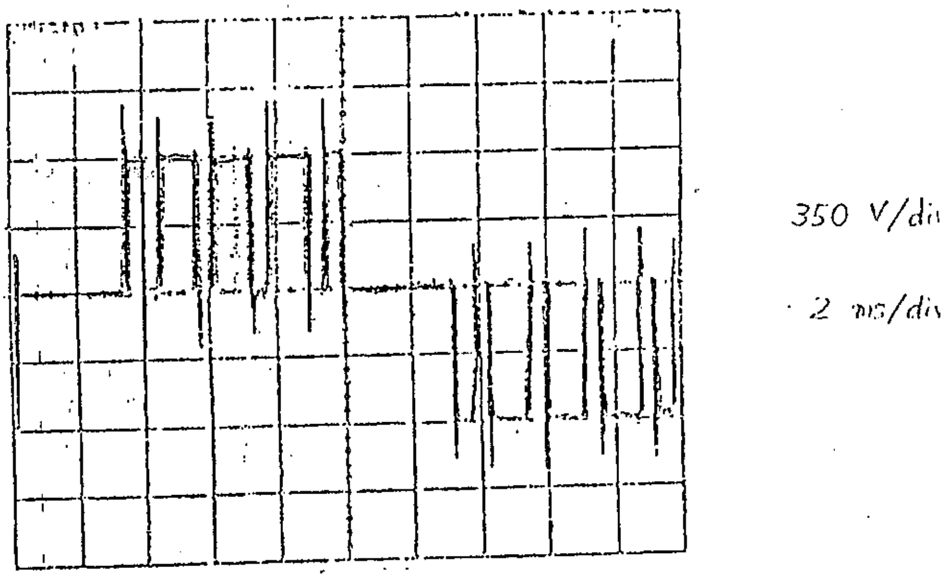


(6–a) VOLTAGE WAVEFORM

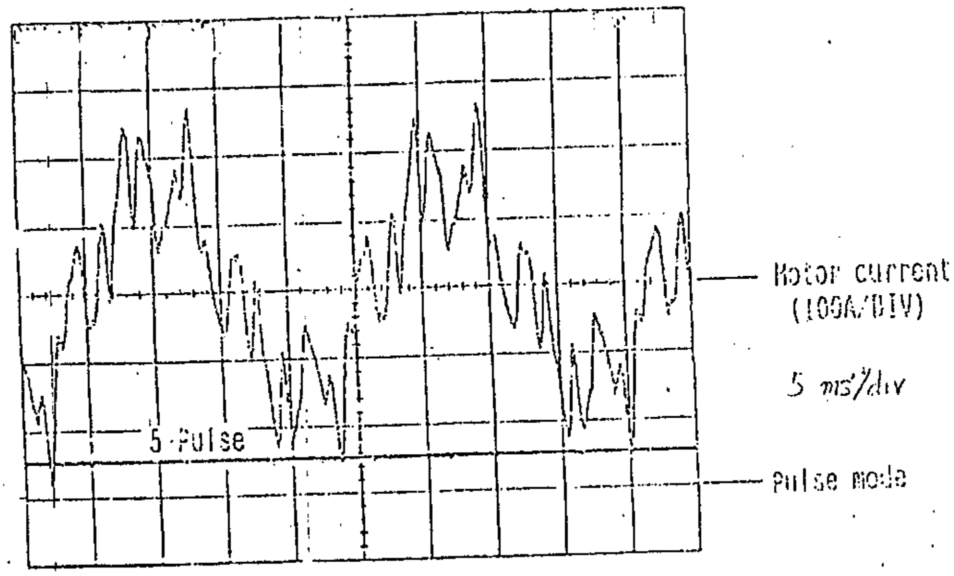


(6–b) CURRENT WAVEFORM

Fig.6 The voltage and current waveforms under the "1 Pulse Modulation Mode".



(7-a) VOLTAGE WAVEFORM



(7-b) CURRENT WAVEFORM

Fig 7 The voltage and current waveforms under the "5 Pulse Modulation Mode".

بسم الله الرحمن الرحيم

التحكم الكامل للمحول الدوار – الرقمى بنظام تعديل إتساع النبضة

الملخص :

فى أنظمة النقل بالكتله الحديثه أصبح التحويل من تيار متردد / تيار مستمر / تيار متردد الأكثر شيوعا فى تطبيقات الجر الكهربى .

ويمكن بهذه الطريقه إمكانية إستخدام محركات التيار المتردد للميزات التى تمتاز بها عن محركات التيار المستمر .

أن مصدر التيار المتردد الأول يمكن الحصول عليه من الشبكه العامه ثم بواسطة المحولات العادية يمكن الحصول على الجهد المستمر .
والمصدر الثانى للتيار المتردد يمكن توليده من الجهد المستمر بواسطة المحول الدوار لنحصل على جهد متردد " ذو تحكم " فى بعض التطبيقات يكون الجهد المتردد ثابت القيمة ومتغير التردد أو متغير القيمة والتردد . وهو بهذه الصورة يصبح مناسبا لإمكانية التحكم الكامل فى السرعه .

وفى هذا البحث تم شرح النظام تفصيليا وتقديم النموذج الرياضى المستنبط وكذا النتائج الفعلية والمحاكاه .