Eng. Research Bull.
Faculty of Eng. & Tech.
Menoufia University
Vol. VI Part 1,1984

pp. 237 - 246

PREDICTION OF INTERNAL RESISTANCE FOR THREE PHASE UNCONTROLLED CONVERTER

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ABSTRACT

The present paper deals with a system consists of three-phase diodes converter connected to an infinite bus through a transformer. The analysis of the short circuit current produced in the converter is carried out, the a.c. network resistance and also the resistance of the d.c. side are taken into account. In addition, the voltage drop across the diodes is considered. A simple method to determine the internal resistance corresponding to the diodes voltage drop has been developed. Experimental results of the short circuit current are obtained to verify the analytical results.

LIST OF SYMBOLS

L	AC network inductance
λ	Smoothing inductance
ω	AC network angular frequency
I_d	Average d.c current
V_d	Average d.c voltage
V	RMS value of a.c phase voltage
V_{do}	Open circuit d.c. voltage
I_{do}	Maximum short circuit current
K	$= I_d/I_{do}$

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1. *INTRODUCTION*

During recent years, the number of semiconductor rectifiers installed in industrial plants and domestic applications have increased [1].

The limitation of the over current produced by the short circuit in the rectifiers is obtained by the connection of a series inductance at the d.c. terminals [2, 3].

The external characteristic of a controlled rectifier bridge fed by synchronous generator can be obtained for different firing angles [4]. In the usual analysis of short circuit of a three phase bridge rectifier, the source is assumed to be an infinite bus and the voltage drop across the diodes is neglected. The short circuit current obtained expirementally is different from that calculated analytically [5, 6]. This difference is due to the inexact analytical simulation of the a.c. network resistances and also the resistances on the d.c. side. Another parameter which presents an essential cause for this difference is the voltage drop across the diodes. All these parameters must be considered in the analysis.

In this paper, the analysis of short circuit current produced in the converter taking into account all previous resistances and the internal resistance corresponding to the diodes voltage drop will be determined. Experimental results of the short circuit current are obtained to verify the analytical results.

2. *PRINCIPLES OF OPERATION*

Figure (1) shows the connection diagram of the diodes-rectifier bridge to be studied. Switch S_2 is opened when the resistance r is taken into account. Switch S_1 closed for short circuit calculations.

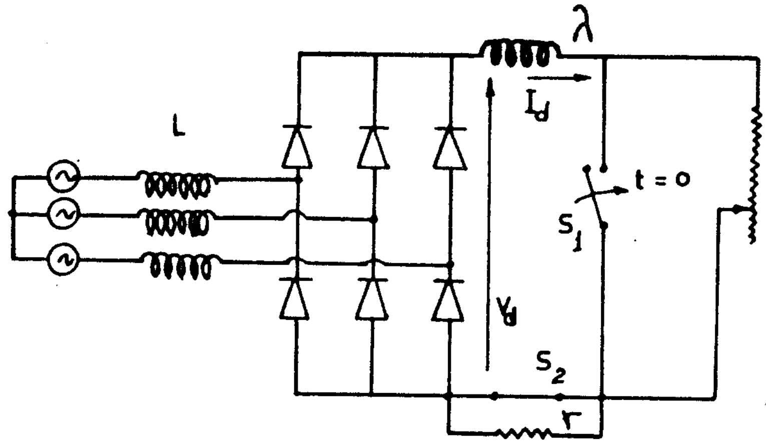


Figure (1) : System connection diagram

Due to commutation phenomena (neglecting the voltage drop across the diodes) the d.c. output voltage is given by

$$V_d = \frac{V_{do}}{2} (1 + \cos u) \qquad (1)$$

where u is the commutation angle.

The external characteristic shown in Figure (2) can be described by the following three modes of operation :

2.1. Mode 1 : $u \leq \frac{\pi}{3}$

Two or three diodes are conducting, the characteristic of this mode can be represented by the following straight line equation (portion ab of Figure 2) :

$$V_d = V_{do} \left[1 - (I_d/\sqrt{3}\, I_{do})\right] \qquad (2)$$

where $V_{do} = 3\sqrt{6}\, V/\pi$, $I_{do} = \sqrt{2}\, V/\omega L$

From Equations (1) and (2), the limits of this mode are defined by :

$$\frac{3}{4} < (V_d/V_{do}) < 1 \quad \text{and} \quad 0 < (I_d/I_{do}) < \frac{\sqrt{3}}{4}$$

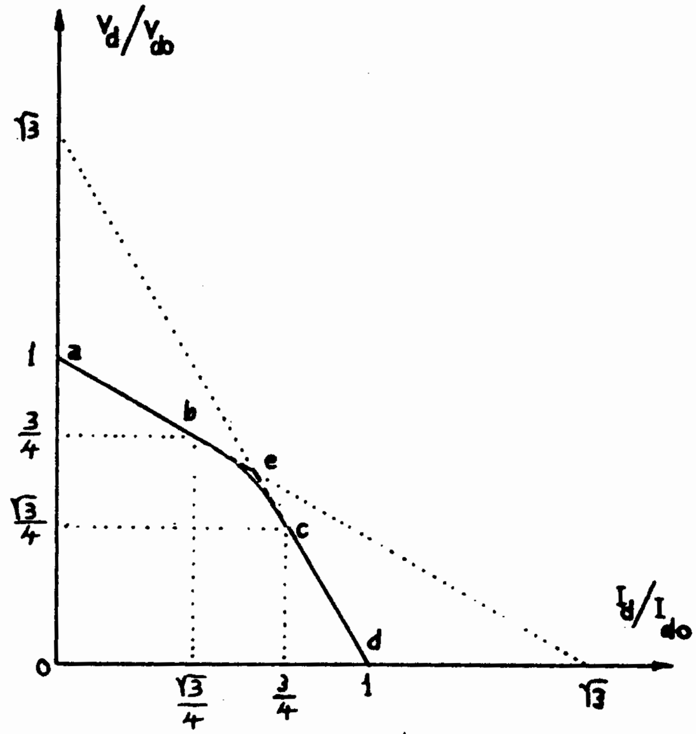


Figure (2) : Rectifier external characteristic

2.2. Mode 2 : $u = \frac{\pi}{3}$

Three diodes are conducting and the d.c. output voltage and the average rectified current are determined by the following Equations [4]

$$V_d = \frac{\sqrt{3}}{2} V_{do} \cos \phi \quad (3)$$

$$I_d = \frac{\sqrt{3}}{2} I_{do} \sin \phi \quad (4)$$

where ϕ is the phase delay angle due to commutation. From Equations (3, 4), the external characteristic of this mode can be represented by a circle. ϕ may be varied from $\pi/6$ to $\pi/3$, and the portion of the external characteristic (are bc in Figure 2) coincide with the circle whose center is at the origin, with a radius $\sqrt{3}/2$.

The limits of this mode are defined by

$$\frac{\sqrt{3}}{4} < (V_d/V_{do}) < \frac{3}{4} \text{ and } \frac{\sqrt{3}}{4} < (I_d/I_{do}) < \frac{3}{4}$$

2.3. *Mode 3* : $u > \frac{\pi}{3}$

This mode of operation occurs when three or four diodes are conducting.
The average d.c. output voltage is given by

$$V_d = \sqrt{3} \ V_{do} \ [1 - (I_d/I_{do})] \qquad (5)$$

The external characteristic of this mode is represented by the line cd in Figure (2), and its limite are defined by

$$0 < (V_d/V_{do}) < \frac{\sqrt{3}}{4} \quad \text{and} \quad \frac{3}{4} < (I_d/I_{do}) < 1$$

The circular portion of the characteristic is approximated by two straight lines (be, ce) and the external characteristic becomes the two straight lines abe and ecd. From Equations (2, 5), point e is defined by :

$$\frac{V_d}{V_{do}} = \frac{I_d}{I_{do}} = \frac{3-\sqrt{3}}{2} = 0.634$$

3. *THEORETICAL ANALYSIS* :

The rectifier circuitry introduces nonlinearities in any exact analysis. However, an exact analysis is tedious, consequently, circuit analysis can be developed, using the characteristic shown in Figure (2), from which a satisfactory prediction of the performance can be obtained.

3.1. *Short - Circuit Analysis*

This analysis depends essentially on the external characteristic of the system (Fig. 2). It is carried out in two main approaches :

A. Firstly, when there is no resistance in the d.c. side and its terminals are short circuited.

1. For $0 < I_d / I_{do} \leq 0.634$ (line abe).

The rectifier is represented by a d.c. source (V_{do}) in series with a resistance ($R_1 = V_{d0}/\sqrt{3} \ I_{do}$) and an inductance ($\lambda$), then the instantaneous current is expressed as :

$$i_d = \sqrt{3}\, I_{do}\, (1 - e^{-t/\tau_1}) + I_d \qquad (6)$$

where

$$\tau_1 = \frac{\lambda}{R_1} = \frac{\pi}{3} \frac{\lambda}{\omega L}$$

2. For $0.634 < I_d/I_{do} < 1$ (line ecd)

The rectifier is represented by a d.c. source ($\sqrt{3}$ V_{do}) inseries with a resistance ($R_2 = \sqrt{3}\, V_{do}/I_{do}$) and an inductance ($\lambda$), then

$$i_d = I_{do}\, (1.634 - e^{-t/\tau_2}) \qquad (7)$$

where

$$\tau_2 = \frac{\lambda}{R_2} = \frac{\lambda}{3\, R_1} = \frac{\tau_1}{3}$$

This current starts with an initial value of 0.634 I_{do}.

B. Secondly, when the resistance r in the d.c. side is considered, the short circuit current will be limited by this resistance, and the maximum short circuit current becomes K I_{do} instead of I_{do}, where $0 < K < 1$. Therefore

$$r = \frac{V_d}{I_d} = \sqrt{3}\, \frac{1-K}{K} \frac{V_{do}}{I_{do}} = \frac{9}{\pi} \frac{1-K}{K}\, \omega L$$

1. For $0 < \frac{I_d}{I_{do}} \leq 0.634$, the rectifier is then represented by a d.c. source (V_{do}) in series with a resistance (R_3) and an inductance (λ).

   where

$$R_3 = R_1 + r = \frac{3}{\pi} \left(\frac{3-2\,K}{K} \right) \omega L$$

   and

$$id = \frac{\sqrt{3}\, K}{3-2\,K}\, I_{do}\, (1 - e^{-t/\tau_3}) + I_d \qquad (8)$$

$$\tau_3 = \frac{\lambda}{R_1 + r} = \frac{K\, T_1}{3-2\,K}$$

2. For $0.634 < \frac{I_d}{I_{do}} < 1$, the rectifier is represented by a d.c. source ($\sqrt{3}$ V_{do}) in series with a resistance (R_4) and an inductance (λ).

where

$$R_4 = R_2 + r = \frac{9}{\pi} \frac{\omega L}{K}$$

and

$$i_d = I_{do} \left[K(1 - e^{-t/\tau_4}) + 0.634\right] \qquad (9)$$

$$\tau_4 = K \frac{\tau_1}{3}$$

Figure (3) shows the short circuit current which is limited by the resistance r in the d.c. side.

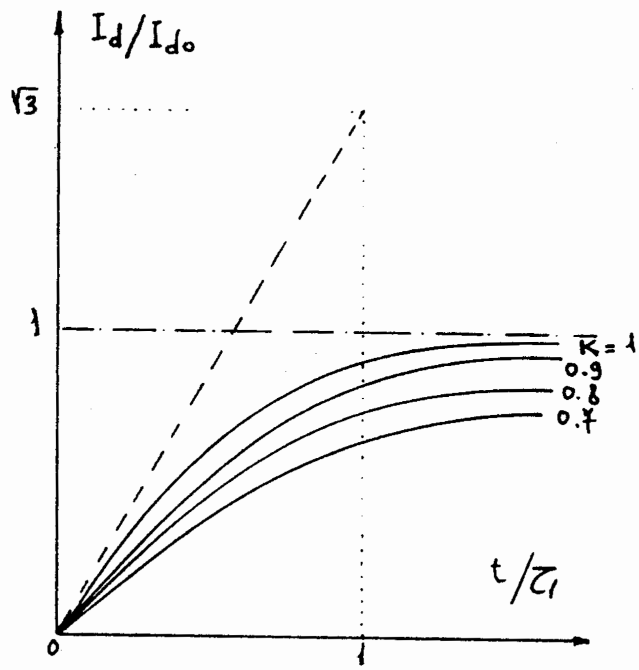


Figure (3) : Short circuit current when r is considered

3.2. Internal Diodes Resistance

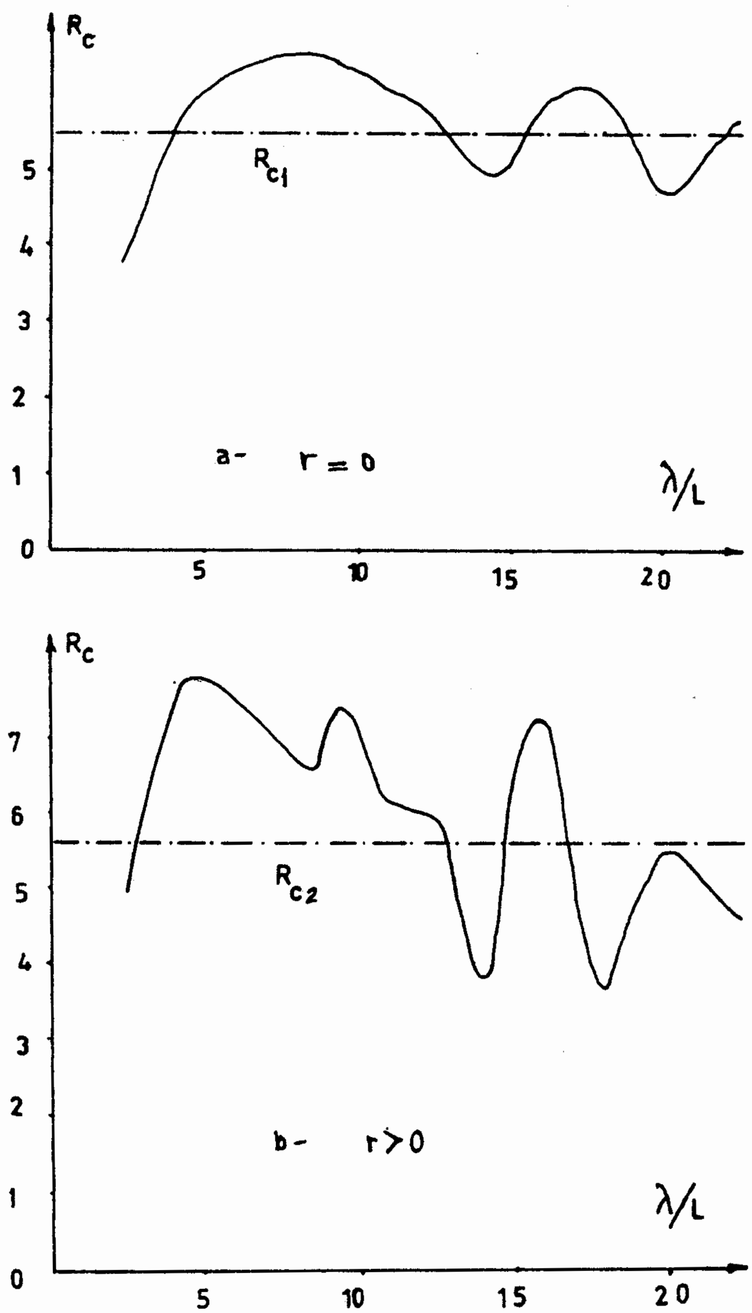
As discussed in the previous section, the total equivalent resistance of the system can be expressed by :

$$R = r + R_d + R_m + R_a + R_c$$

where

- r : is the external resistance at the d.c. side;
- R_d : resistance of the smoothing inductance.
- R_m : resistance of the measuring elements;
- R_a : resistance of the a.c. side ;
- R_c : resistance corresponding to diodes voltage drop.

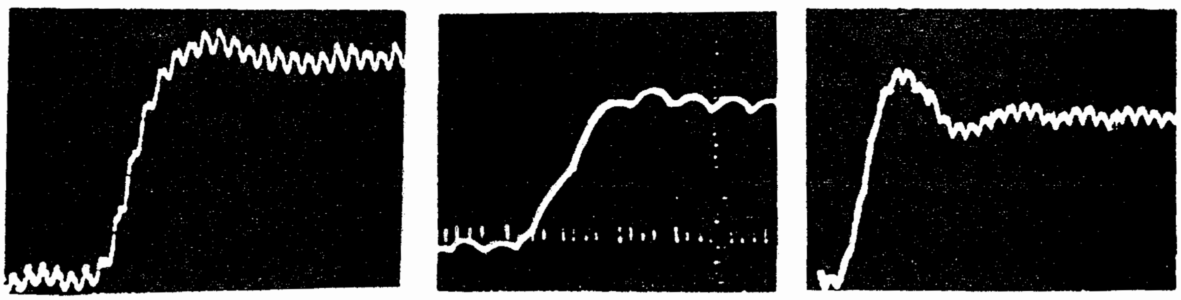
Two curves are obtained for R_c as a function of λ/L. The first one, with resistance r neglected Figure (4-a), and the mean value R_{c1} is evaluated. The second curve shows the relation when resistance r is considered Figure (4-b), and the mean value R_{c2} is evaluated. It can be observed that, there is a vary small difference between R_{c1} and R_{c2}. However, any one of these two values can be taken as the mean value of the internal diodes resistance.



Figure(4): Diodes internal resistance as a function of(λ,L)

4. *EXPERIMENTAL RESULTS*

A three-phase diodes bridge rectifier is used to experimentally study the short circuit d.c. current. When the rectifier supplies its current to the load resistance Figure (1), switch S_1 is suddenly closed across the load resistance to permit the measurement of the short circuit current. When $\lambda/L = 4.4$, the initial over current (over-shoot) was very small and damped very slowly Figure(5-a). When $\lambda/L = 9$, there was no over current Figure (5-b), and this result approximately the same as that obtained analytically in Figure (3). When $\lambda/L = 12$, there was an initial over current which damped rapidly Figure(5-c).



(a) (b) (c)

Figure (5): Experimental short circuit d.c. current

5. *CONCLUSION*

The good choise of the ratio between the smoothing inductance and the equivalent inductance on the a.c. side of the converter system, will reduce the magnitude of the over current produced by the short circuit on the diode rectifier. A method for predicting the equivalent internal resistance of diodes is presented. The obtained results do not differ significantly whether an external resistance in the d.c. side does exist or not. The method used in this paper can also be applied to any controlled rectifier for predicting its internal resistance and also to study the influence of the firing angle on this resistance.

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