A NOVEL HIGH-POWER HIGH-EFFICIENCY RECTIFIER SYSTEM FOR ELECTROCHEMICAL PLANTS

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Keywords: Electrochemical Plants, ac/dc Rectifiers, Switching dc/dc Power Supplies.

Abstract. **A novel design of a rectifier system is proposed suitable for electrochemical plants with very large current ratings. Essentially, a promising multi-pulse ac/dc rectifier circuit is connected in cascade to a switching dc/dc circuit, the latter acting as a current amplifier. The whole rectifier system is expected to yield high efficiency from the economical and technical point of view.**

I. INTRODUCTION

It is a well-known property of rectifier systems that they produce distortion of current waves on the ac supply system. It is also generally recognized that all wave distortions cause increased operating costs in motors, malfunction of protective devices and increased losses in all system components [1]. In order to diminish distortion, large electrochemical rectifier systems are usually made up of several six-pulse rectifiers, with appropriate phase shift, to get a higher pulse number.

The proposed rectifier system in this paper involves two conversion stages, a multi-pulse ac/dc rectifier circuit and a switching dc/dc circuit, both connected in cascade, the latter used as a current amplifier.

The multi-pulse technique, applied in the first stage of conversion, is a promising technique aiming for a high number of pulses without the complicated circuitry involved in conventional techniques. This appeared in the early 1970`s [4], [5], whereby harmonic reduction was carried out by adding a harmonic current from an external source. Further developments into the technique avoided the use of the external source [6], [7], and particularly in [7] an interesting generalization was attempted. Finally, in [8] a complete theoretical treatment was achieved demonstrating all the potential that the technique can be put to.

The second stage of conversion involves a current amplification, carried out with a switching dc/dc circuit in order to get very high levels of current. Thus, the switching dc/dc circuit avoids stressing the multi-pulse configuration, which probably would collapse due to very large commutation times of thyristors when these are exposed to high currents.

Switching dc/dc circuits are reaching great popularity nowadays, because they provide high power density due to reduction of size and weight and high conversion efficiency because of their high frequency operation.

The application of both multi-pulse and switching techniques to high-power rectifier systems used in electrochemical installations is addressed in this paper. It is expected that the whole system will yield advantages in design, plant compactness, efficiency and an accurate harmonic elimination on both the dc and ac sides.

II. CONVENTIONAL AND PROPOSED CONFIGURATIONS FOR HIGH POWER APPLICATIONS

The conventional design of high-power rectifier systems used in electrochemical installations is made up of several 3-phase transformers and 6-pulse rectifier bridges. For example, a traditional 48-pulse rectifier system requires 8 three-phase transformers and 8 six-pulse rectifier bridges, with enough parallel paths to cater for the high currents involved. Additionally a careful phase shift must be provided to create a balanced higher pulse system.

On the other hand the 48-pulse configuration proposed in this paper involves 2

three-phase transformers, 2 six-pulse rectifier bridges, a thyristor-tapped reactor and a switching dc/dc circuit. It is expected that the proposed configuration will provide advantages from the economical and technical point of view. Additionally the harmonic cancellation is expected to be accurate which is not always guaranteed with the conventional technique [9].

III. FIRST STAGE. THE MULTI-PULSE AC/DC RECTIFIER

Fig. 1 shows the circuit configuration and typical waveforms of the multi-pulse ac/dc rectifier. The waveforms are experimental results carried out in a 2-kW laboratory model. Diagrams were taken using a signal analyzer HP-3561 and a normal oscilloscope.

The theoretical and experimental bases of the technique are given in [8]. It is demonstrated that the 48-pulse configuration shown in Fig. 1 is just a particular case of a general theory. That is, the number of thyristors in the interphase reactor may be "n" and the converters at both sides of the interphase reactor may be of "p" pulses. Thus, the total number of pulses obtained is "2pn". This is achieved by natural commutation and is equally valid for rectification and inversion. In the particular case of Fig. 1 the following applies:

$$n = 4$$
$$p = 6$$
$$Total\ \#\ of\ pulses = 48$$

In case of "n" thyristors in the interphase reactor, the location of thyristor "q" is given by:

$$\frac{N_q}{N_o} = \frac{tan\left|\frac{\pi}{2np}(n+1-2q)\right|}{2\,tan\left(\frac{\pi}{2p}\right)} \quad ; \quad q = 1,2,3,...,n \qquad (1)$$

where:

n : Total number of thyristors
p : Number of pulses of both converters
N_0: Total number of turns of interphase reactor.
N_q: Position of thyristor "q", measured in number of turns from the center of interphase reactor.

It is also demonstrated in [8] that there is a minimum condition for α to enable the reactor thyristors to turn on by natural commutation, that is:

$$\alpha_{min} = \frac{\pi}{p}\left(\frac{1}{2} - \frac{1}{n}\right) \qquad (2)$$

In the particular case of Fig. 1 the following applies:

$$\alpha_{min} = 7.5^{o} \quad ; \quad \frac{Na}{No} = 0.3712 \quad ; \quad \frac{Nb}{No} = 0.122$$

IV. SECOND STAGE. THE SWITCHING DC/DC CIRCUIT

Fig. 2 shows the circuit configuration and typical waveforms of the switching dc/dc circuit. The waveforms are computer results using the SPICE7.1 program as a simulation tool. In the following important concepts are outlined regarding the switching technique.

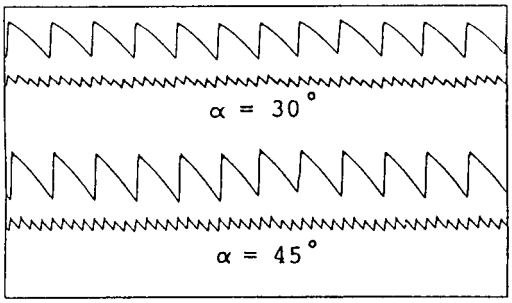
Advances in the semiconductor technology have lead to a widespread use of switching power supplies. These circuits employ solid state devices and increased switching speeds, higher voltage and current ratings and a relatively lower cost of these devices are the factors that have contributed to the emergence of switching power supplies. On the negative side, switching supplies are more complex, and proper measures must be taken to prevent EMI due to high frequency switchings [10]. The most important components of a switching power supply are considered in the following:

A. Power semiconductor devices

At present the most important semiconductor devices in switching power supplies are:

a) Insulated Gate Bipolar Transistors. Over the last 10 years a significant reduction in conducting and switching losses in IGBT`s has been achieved. At present voltages of 600, 1200 and 1700 V and current ratings up to 600 A or more are available [11].

b) Gate-Turn-Off (GTO) Thyristors. GTO thyristors rated at 6 KV and 6 KA, fabricated on a silicon wafer with a 6-inch diameter are now available for utility/industry applications [11].



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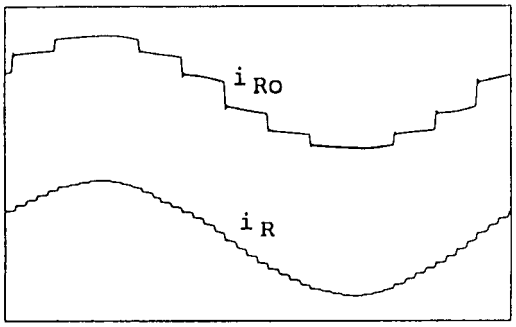

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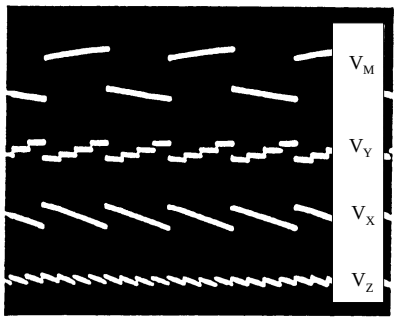

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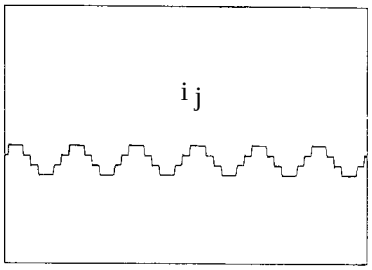

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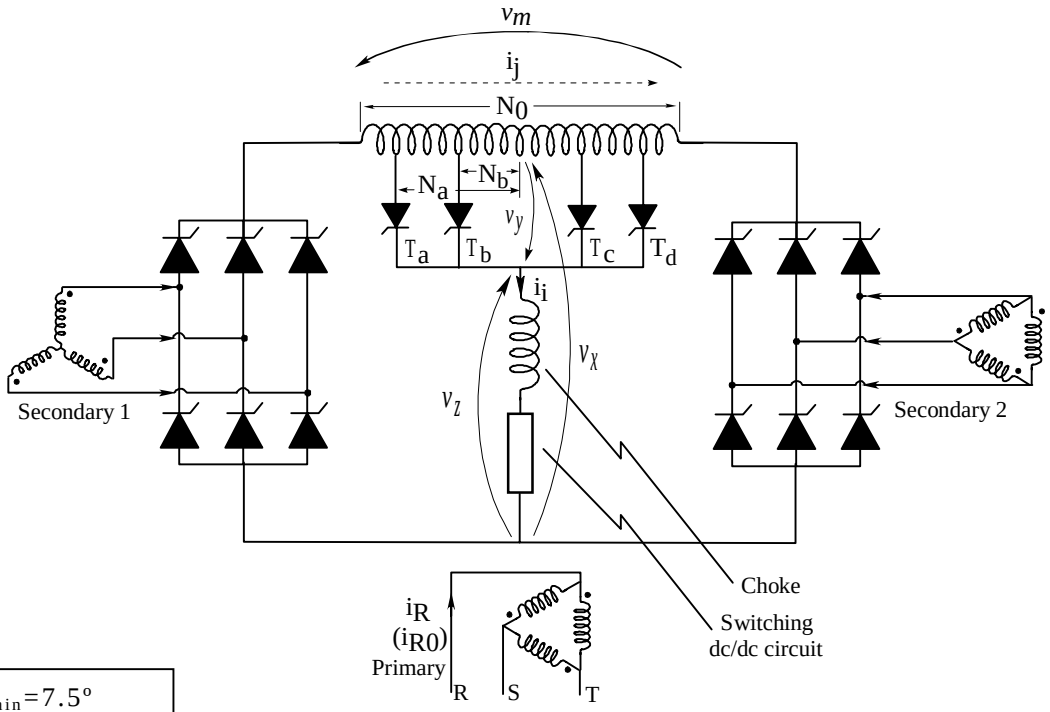


α_{min}=7.5°
N_a/N_0=0.3712
N_b/N_0 =0.122
n=4
p=6
pz=48

Fig.1. Transformation of pulses from 12 to 48.

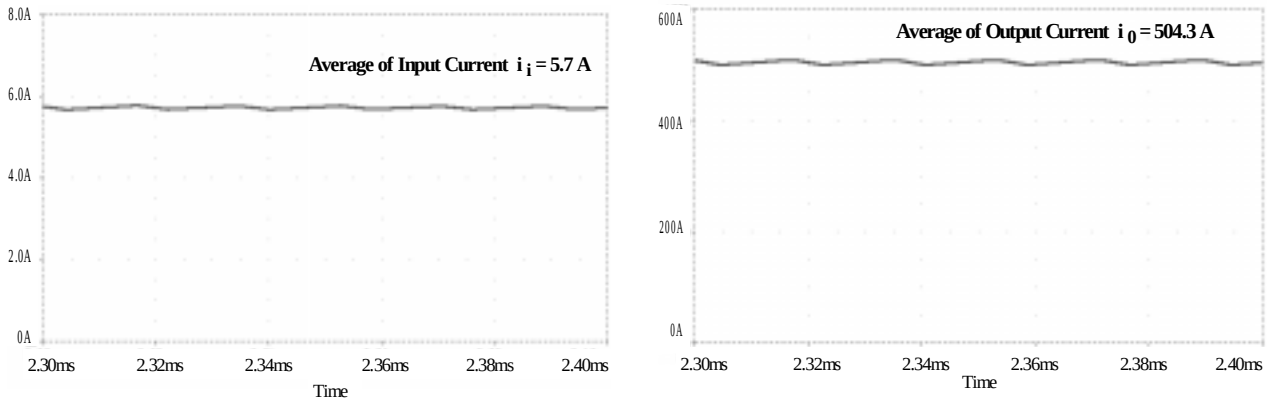
a) v_X and v_Z at different firing angles

b) AC currents for conventional (i_{Ro}) and modified (i_R) configurations

c) Oscilloscope waveforms of voltages v_M, v_Y, v_X and v_Z

d) Current i_j

e) Circuit configuration.



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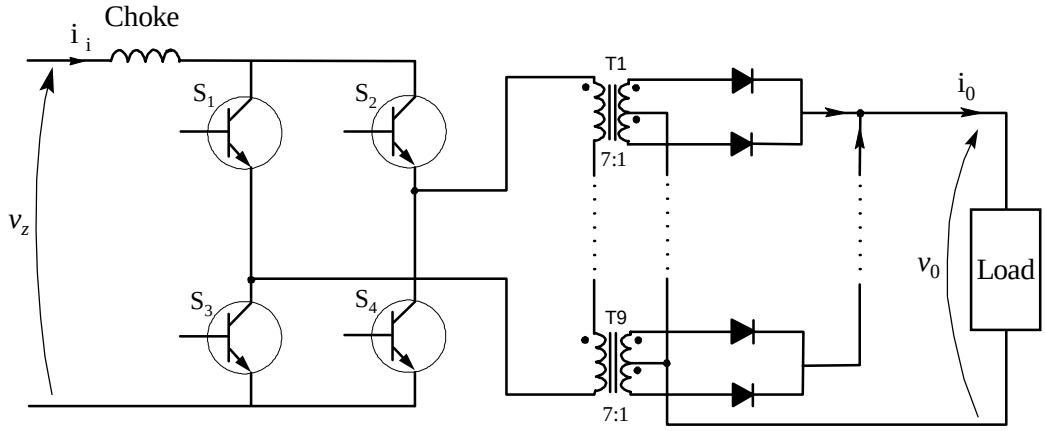

c)

Fig.2. Switching dc/dc circuit.

a) Input current (i_i)
b) Output current (i_0)
c) Circuit configuration.

B. High frequency transformers

Operating transformers at high frequency presents unique designs problems, owing to the increased importance of core loss and leakage inductance. High frequency transformer designs therefore require considerable more care in specifying the type of core and winding, because the physical orientation and spacing of the windings determine leakage inductance.

Toroidal cores are normally chosen because of the very low stray flux and low leakage inductance. These are achieved because the magnetic flux in the toroid can be contained within the core and the windings cover the core along the entire magnetic path length. Ferrites have been almost exclusively used as the magnetic material in high frequency power transformers.

Another important consideration in designing transformers at high frequency is eddy currents losses in the copper wire due to the “skin effect” and further evaluation of conductor size must be carried out [12].

C. *High frequency output rectifiers*

A high frequency, high current and low voltage switching power supply demands that output rectifier diodes must have a low forward voltage drop, fast recovery characteristics and adequate power handling capability. Three types of rectifier diodes are commonly used in switching power supplies [13]:

- High-efficiency fast recovery
- High-efficiency very fast recovery
- Schottky

V. COMPUTER SIMULATION OF THE SWITCHING DC/DC CIRCUIT

The use of computer simulation techniques provides a means to gain a better understanding of the possible performance of a power electronic system. A number of general purpose circuit analysis programs, such as ECAP, SCEPTRE and SPICE can be used to simulate power electronics systems [14].

The SPICE7.1 program was used to simulate the switching dc/dc circuit and the following parameters were considered:

Input voltage	: 330 V
Smoothing inductor	: 1 uH
Switching frequency	: 27 kHz
Primary inductance	: 1.2 mH
Secondary inductance	: 2×25 uH
Average output voltage	: 3 V
Load Resistance	: 5.5 mΩ

VI. COMPARISON BETWEEN PROPOSED AND CONVENTIONAL CONFIGURATIONS

Large electrochemical rectifier systems are usually made up of several 6-pulse rectifiers with appropriate phase shift to create balanced higher pulse systems. Transformer phase-shifting in multi-converter configurations, however, are normally bulky and associated with complicated transformer connections. Moreover, harmonic elimination is not complete because there will always be residual harmonics due to imperfect transformer phase shift, impedance unbalances, or unequal phase retard of thyristors.

In this regard, the less complicated circuitry of the proposed configuration, in comparison with the conventional one, is expected to provide a better harmonic cancellation, improve energy efficiency and provide flexibility for a more economic hardware design.

VII. CONCLUSIONS

A new concept of rectifier systems has been proposed for electrochemical installations involving very high current ratings. The application considers two stages of conversion, a multi-pulse and a switching stage connected in cascade. Through experimental work and computer simulation it was shown that the scheme is possible and advantages over the conventional configuration are expected regarding compactness, efficiency and harmonic cancellation.

The results so far achieved are sufficiently encouraging to merit a thorough comparison with conventional alternatives. Further studies will be carried out to assess the behaviour and overall efficiency of the proposed configuration using laboratory models along with computer simulation.

ACKNOWLEDGMENTS

The authors would like to express their most sincere gratitude to those people, listed in the References, who in the past years have greatly contributed to the advancement of the technique applied in this paper.

They would also like to express their gratitude to DICYT of Santiago University of Chile and FONDECYT (Project Nº 1980661), for their financial support as well.

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