TUTORIAL: THE M-BRIDGE AND THE UNIVERSAL POWER CONVERTER

Denise Gerardi **Wail M. Pastorello Filho**
Research and Development Group
NOTRE DAME Engenharia Ltda.
89.120-000 - Timbó - SC - Brasil
email: wail@ndeng.com.br

***Abstract* – This work introduces a new bridge of power switches, the M-Bridge, whose structure is applied to obtain a Universal Power Converter. The Tutorial presentation has the objective of describe the theoretical aspects and the operation principle of the M-Bridge. In order to have a clear interpretation of the structure behavior, the analysis is done using concepts of different knowledge areas, like Power Electronics and Systems Communication. The models were evaluated through numerical simulation and the results confirm the operation principle as well as the potential of the proposed structure.**

***Keywords* – M-Bridge, power balanced modulation, power synchronous demodulation and universal power converter.**

I. INTRODUCTION

The idea of a Universal Power Converter, which is able to implement any kind of conversion, ends in a basic principle of Power Electronics that is the current recirculation. From the simplest to the most complex converter, the recirculation process is always present in some way on the structure. The electronic component that makes this important function is an uncontrolled switch, called free-wheeling diode.

However, in a structure that uses bidirectional power switches, the free-wheeling process can not be fully accomplished. The reason for this statement is that a bidirectional power switch does not allow a current flow without a turn-on command. On this case, when the free-wheeling loop has a bidirectional power switch, the turn-on and the turn-off commands must be controlled.

Since the current recirculation does not contribute to the transference of energy between input and output, the free-wheeling process must start naturally in the moment that the commanded switches are turned-off. This work introduces a new Bridge structure, named M-Bridge, which has the capability to implement an uncontrolled current recirculation when bidirectional power switches are used. From this Bridge it is possible to achieve a Universal Power Converter, whose genesis is presented in the following items.

II. THE M-BRIDGE

The best way to describe the M-Bridge is define it as a Power Balanced Modulator. In other words, this bridge can generate a power signal of Amplitude-Modulated, Double Side Band and Suppressed Carrier [1] [2], that is, an AM-DSB-SC power signal. The operation principle of this modulator can be understood studying its operation stages.

The M-Bridge structure is introduced on Fig. 1. It has four bidirectional (voltage and current) power switches, two free-wheeling diodes and a high frequency transformer with two primary windings. In order to help the operation analysis, the secondary winding is also represented on Fig. 1.

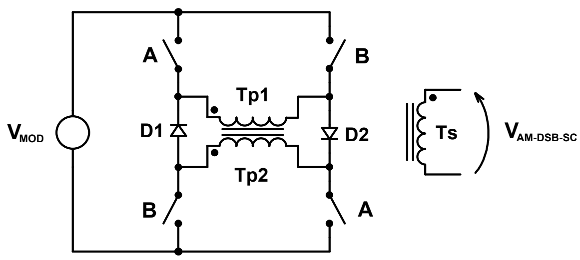

Fig. 1. – The M-Bridge.

Observing the diagram on Fig. 1, it can be identified three basic stages of operation, depending on the conduction state of the bidirectional power switches. The first one is characterized by the conduction of "**A**" switches, while the others are kept on off-state. The second stage is characterized by the conduction of "**B**" switches, while the others are kept on off-state. On the third stage all switches are off. Evidently, the diodes state will change naturally according to the current behavior.

Applying on the M-Bridge input a Modulating Signal, for example a voltage sine waveform, and using an appropriate rule to control the power switches, the voltage on the transformer secondary will be an AM-DSB-SC signal. The switches control rule is represented by the command pulses on Fig. 2.a and Fig. 2.b. The Modulating Signal and AM-DSB-SC signal are presented on Fig. 3.

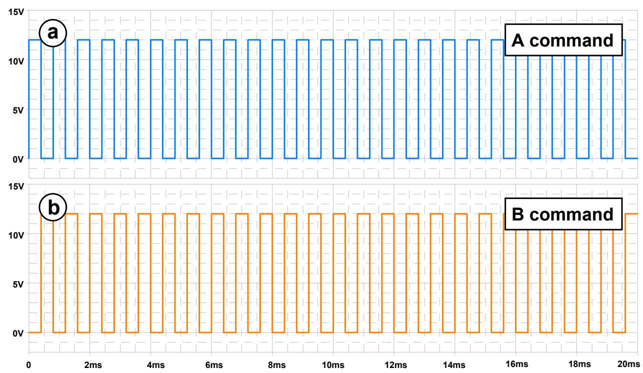

Fig. 2. – Command waveforms for switches A and B.

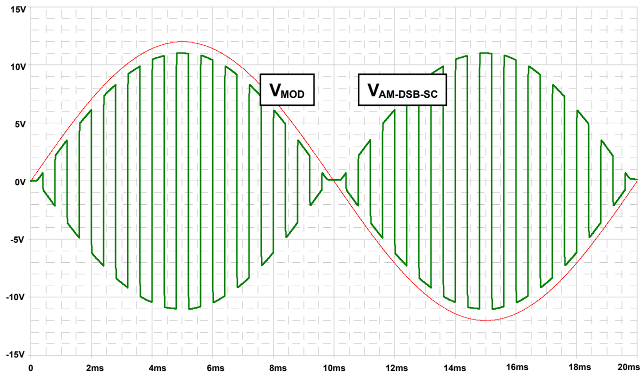

Fig. 3. – Modulating Signal and AM-DSB-SC Signal.

III. TRANSFORMER ANALISYS

As an introduction of the M-Bridge analysis, it is necessary to emphasize the importance of the transformer in its structure. From the energy transference point of view the M-Bridge can operate in all four quadrants. However, this concept must be extended beyond the input supply and applied to the transformer element, which needs to operate in all four quadrants too. The Fig. 4 shows the four quadrant conditions on the transformer element.

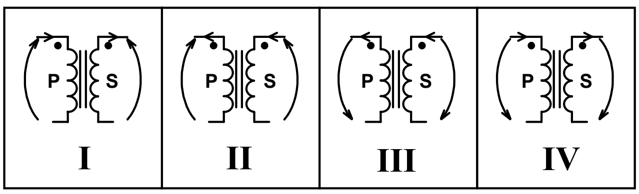

Fig. 4. – Four-quadrants in the transformer analysis.

The operation of the M-Bridge must combine the energy transference condition on the input supply and on the output load reflected to the transformer primary side. Obviously, this combination can not have an effect on the energy flux. Therefore, the operation stages must be established in a suitable sequence according to this statement.

IV. STAGES OF M-BRIDGE

Essentially, the operation principle of the M-Bridge is based on Energy and Power concepts. Energy is an abstract concept that indicates the ability of a system to do Work. Power is a concept related to the Energy transference and is defined by the direction and dynamics of the energy flux in a giving system.

Founding the M-Bridge conception on Energy, it is possible to describe its operation through the way the Power is established. According to the energy flux direction across the converter, three conditions can be defined: ACTIVE, PASSIVE or NEUTRAL.

The ACTIVE condition is characterized by an energy flux from the input supply to the output load. Since the M-Bridge has the transformer element, the flux dynamics is defined by the combined operation of SUPPLY/LOAD. The energy transference occurs in one of the following power quadrants combination: I/I, I/III, III/I e III/III. The four combinations that define the ACTIVE stages are shown in Fig. 5.

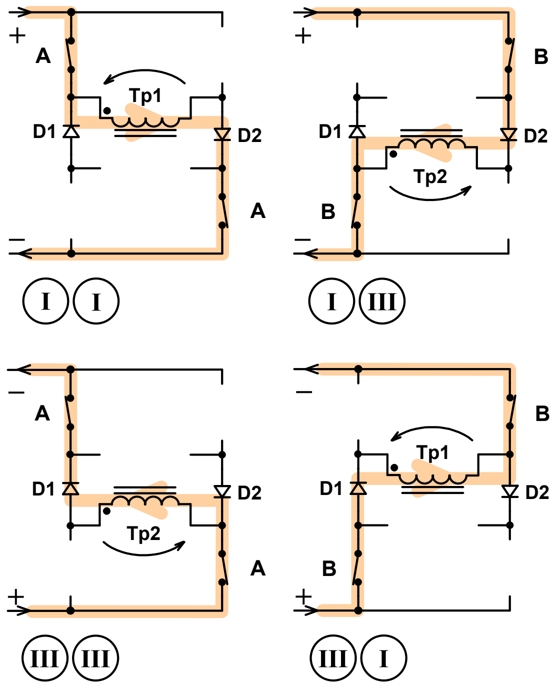

Fig. 5. – Active stages of M-Bridge.

The PASSIVE condition is characterized by an energy flux from the output load to the input supply. Once more the transformer element forces the combined operation between SUPPLY/LOAD. The energy transference occurs in one of the following power quadrants combination: II/II, II/IV, IV/II e IV/IV. The combinations that define the PASSIVE stages are shown in Fig. 6.

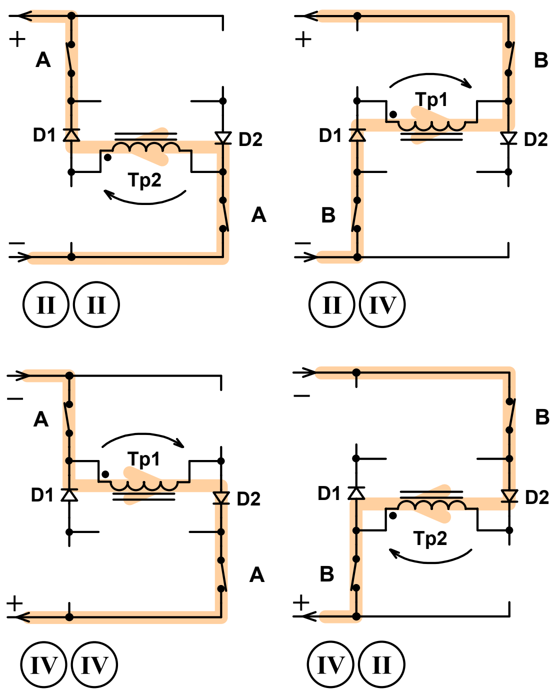

Fig. 6. – Passive stages of M-Bridge.

The NEUTRAL condition is characterized when there is no energy flux between the input supply and output load. All energy stored on the transformer is dissipated due to the magnetic flux cancellation inside of it. The energy stored on the output stage keeps circulating across the output load. The NEUTRAL stage is shown in Fig. 7.

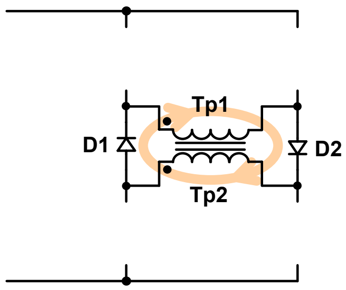

Fig. 7. – Neutral stage of M-Bridge.

The magnetic flux cancellation is caused by the turn-off of all M-Bridge power switches. On this condition, the current that flows through one of the transformer primary winding can not return to the supply neither can be transferred to the load. As a consequence, this current is forced to circulate across the diodes and the other primary winding. This condition creates identical but opposite magnetic fluxes on the transformer core.

V. CLASSES OF CONVERSION

The Power Converter is an intermediary element between a supply and its respective load. In the energy conversion process, the supplied power can be delivered to the load with a different waveform of voltage and current. The changes on the voltage and current forms qualify the Classes of Conversion that are represented in Fig. 8.

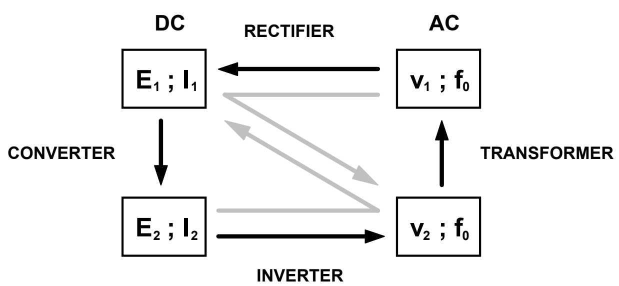

Fig. 8. – Power Conversion Classification.

The conversion processes on Fig. 8 are very well known and have been widely studied in Power Electronics. Despite many converters use more than one process to reach a final conversion, the four basic processes are always analyzed individually. These converters in particular are represented by one of the diagonal lines on the diagram and carry out a process named Indirect Power Conversion.

On the other hand, observing the diagram on Fig. 8 it is expected that a question arises. Could a converter be able to execute the four conversion processes with a unique power stage? This work shows that the answer is positive. The Universal Power Converter, based on the M-Bridge, can go through all the peripheral paths on the power conversion diagram.

VI. THE UNIVERSAL POWER CONVERTER

The most important contribution of the M-Bridge to the power conversion process is that the Carrier, that is, the command signal to the power switches, can be Pulse Width Modulated without affecting the input Modulating Signal. On this way, it is possible to regulate the amount of energy transferred between the converter input and output. The M-Bridge is able to combine the AM-DSB-SC and PWM modulation techniques in the Universal Power Converter genesis.

The Universal Power Converter is an evolution of the Elementary Voltage Step-Down Converter. The operation principle can be described from the Variable Structures Analysis. Fig. 9 shows the two possible structures of the Voltage Step-Down Converter.

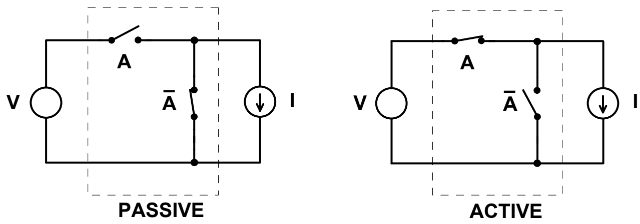

Fig. 9. – Voltage Step-Down Elementary Converter.

In the structure that defines the PASSIVE state, the action of the power supplies is cancelled by the respective switches. The voltage supply does not transfer power, once there is no current circulation. The current supply does not absorb power, once there is no voltage applied to it.

In the structure that defines the ACTIVE state, the power supplies are connected to each other. The amount of transferred power is equal to the product of voltage and current. Both, the supplied and received power, are identical and the energy balance is ideal. The two states, ACTIVE and PASSIVE, can be alternated to regulate the average power transferred from one supply to the other.

The concepts and criteria of Communication Systems applied to the Elementary Voltage Step-Down Converter result in a system that uses the Modulation and Demodulation processes to reach the Universal Power Converter. All elements of this system are presented on the diagram of Fig. 10. The Modulator stage consists of the M-Bridge and the Demodulator stage consists of a Homodyne Detector [1]. The transformer element can be understood like the propagation environment.

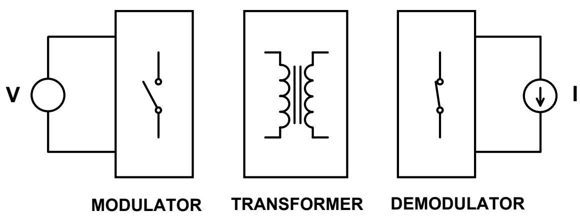

Fig. 10. – Universal Power Converter Architecture.

The Universal Power Converter results from this architecture implemented with controlled and uncontrolled power switches. These elements can be identified on the diagram of Fig. 11. All controlled switches are bidirectional (voltage and current). The power supplies can be AC or DC, independently of each other.

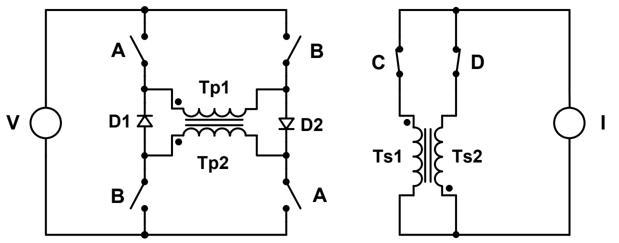

Fig. 11. – Universal Power Converter.

The Modulation process is obtained with a specific command rule applied to the switches "**A**" and "**B**". The Demodulation process is obtained with a specific command rule applied to the switches "**C**" and "**D**". The combination of commands on the Modulator and the Demodulator defines the energy flux path. All the possibilities to the energy flux path were analyzed on Item IV.

The command rules to the Modulation and Demodulation process are not necessary the same. Besides that, there is a specific rule to each one of the four conversion classes. The power stage of the converter is always the same and does not need reconfiguration. The command source must be able to implement any one of the four different rules, according to the conversion class desired.

The main advantage of the Universal Power Converter, conceived from the M-Bridge, is that its operation does not depend on the load features. Since the load presents current source characteristics, the phase angle between output voltage and output current does not affect the conversion process. Besides that, the command rules do not change because of load condition or power nature. As a consequence of this behavior, the Universal Power Converter does not need any kind of voltage or current sensing to adjust the Modulator and Demodulator operation.

VII. SIMULATION RESULTS

The potentiality and efficiency of the Universal Power Converter can be confirmed by numerical simulation. This work presents two applications of the Universal Power Converter. The first one is an AC-AC Voltage Regulator and the second one is a DC-AC Voltage Inverter.

Regarding a Voltage Regulator, the input power supply reproduces the electric main (V_{AC}=110V@50Hz). The load is composed by an inductor L=4mH, a resistor R=2Ω and a capacitor C=10μF, arranged in a series-parallel LRC filter.

The command signals for switches "**A**" and "**B**" are shown in Fig. 12.a and Fig. 12.b, respectively. The command signals for switches "**C**" and "**D**" are shown in Fig. 13.a and Fig. 13.b, respectively.

The main input V_{AC} and the AM-DSB-SC waveforms are shown in Fig. 14. The output voltage and current waveforms are shown in Fig.15.

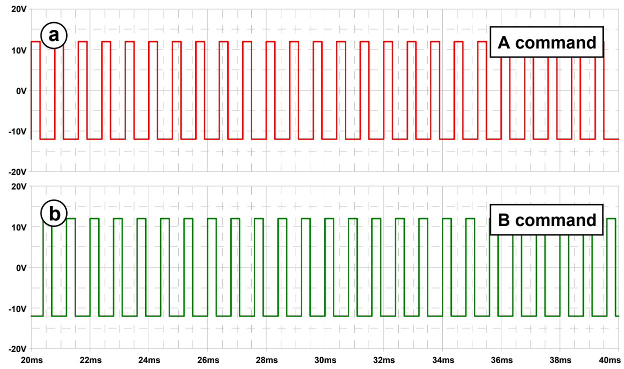

Fig. 12. – Modulator Switches Command.

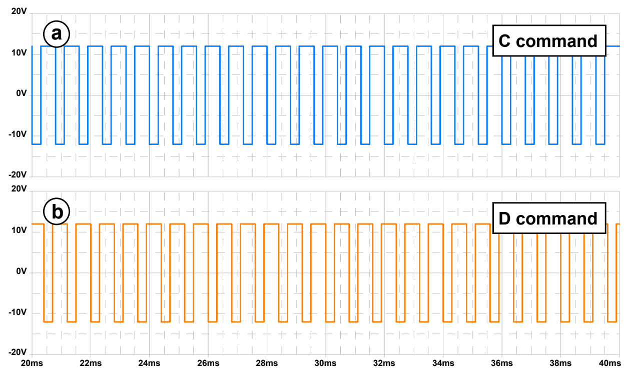

Fig. 13. – Demodulator Switches Command.

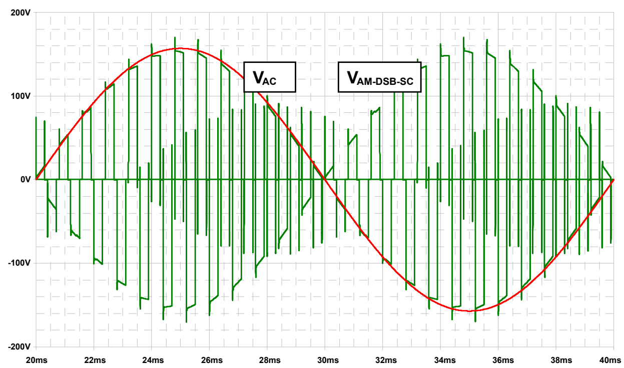

Fig. 14. – Main Voltage and AM-DSB-SC component.

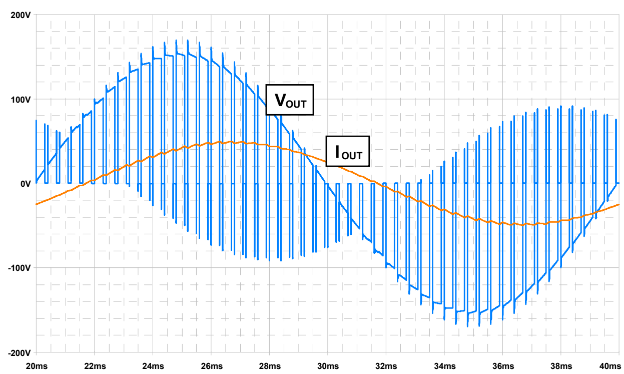

Fig. 15. – Output Voltage and Current

Regarding a Voltage Inverter, the input power supply reproduces a battery bank (V_{DC}=240V). The load is composed by an inductor L=4mH, a resistor R=2Ω and a capacitor C=10μF, arranged in a series-parallel LRC filter.

The command signals for switches "**A**" and "**B**" are shown in Fig. 16.a and Fig. 16.b, respectively. The command signals for switches "**C**" and "**D**" are shown in Fig. 17.a and Fig. 17.b, respectively.

The AC Voltage Reference V_{ACref} and the AM-DSB-SC waveforms are shown in Fig. 18. The output voltage and current waveforms are shown in Fig.19.

VIII. CONCLUSION

In this work, the Power Electronics and Communication Systems concepts were joined together to conceive the M-Bridge and the Universal Power Converter. The M-Bridge was described as a structure capable of combining the AM-DSB-SC and the PWM modulation techniques. From the Modulation and Demodulation processes, it was possible to achieve the Universal Power Converter. The simulation results demonstrated the potentiality of this converter to implement any kind of conversion.

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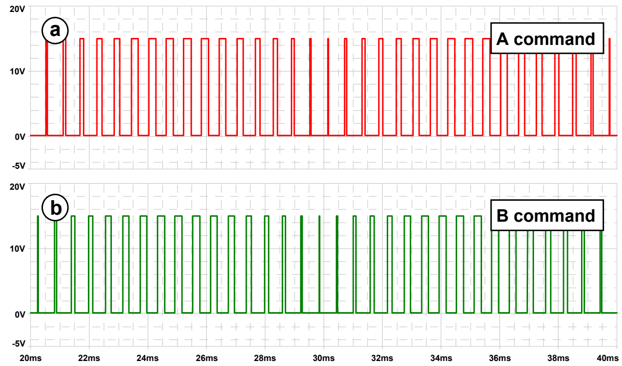

Fig. 16. – Modulator Switches Command.

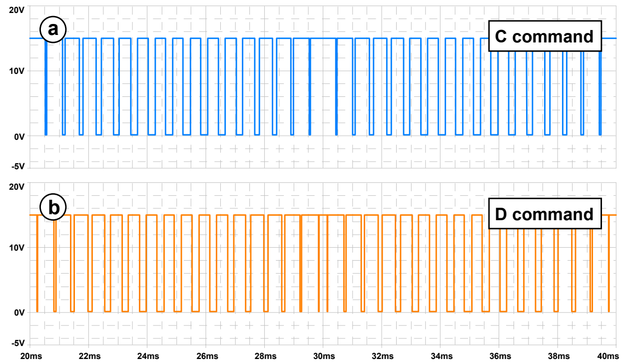

Fig. 17. – Demodulator Switches Command.

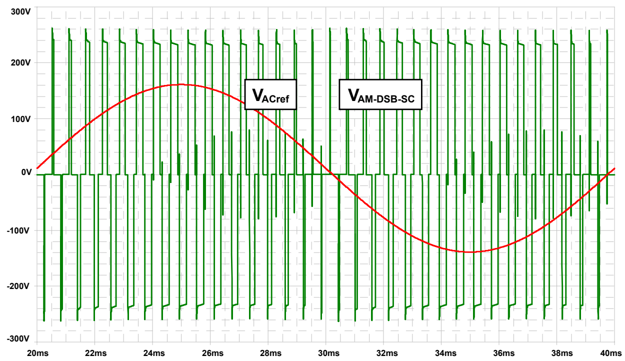

Fig. 18. – Reference Voltage and AM-DSB-SC component.

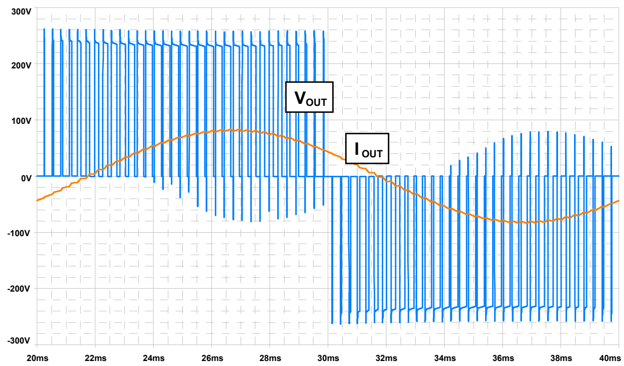

Fig. 19. – Output Voltage and Current