EMTP Tech Notes

for users of the Electromagnetic Transients Program

Issue # 93-2 ***July, 1993*** ***Editor: Thomas Grebe***

in this issue:

Letter from the Editor:

This is the second issue of *EMTP Tech Notes*. The technical newsletter provided to members of the EMTP User's Group. The initial plan for the newsletter is a quarterly technical publication highlighting contributions from members of the User's Group. This newsletter is published using Microsoft Word for Windows. If you wish to contribute an article, please contact me for appropriate text and figure formats. Contributions in the following areas are welcome:

- Technical articles
- Modifications / enhancements to the code
- Case studies / unique simulations
- Research projects
- EMTP data preparation / model development
- Modules developed for distribution on the BBS
- Letters to the editor / User's Group
- Technical paper abstracts
- Questions for members of the User's Group

I believe that the exchange of technical information is one of the most important functions of the EMTP User's Group and this newsletter, in conjunction with *Transients*, will help to serve the needs of the members. Thanks to the authors for helping to put this issue together. As always, I'm open for suggestions regarding this publication and the User's Group in general.

Thanks for your support

For more information concerning the newsletter or to submit a contribution please contact:

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A Oneline Diagram Approach as an Educational Introduction to the use of the EMTP - Introduction

The use of EMTP is now so widespread in the Utility industry that it has become the equivalent of SPICE as a tool of analysis in the context of transient analysis of electric power systems. For universities and Utility training centers therefore courses of instruction concerned with the topic recognize the need to at least expose their students to EMTP. This however presents something of a problem as, despite the enormously and increasingly wide application of EMTP, there is a very long and difficult period required to learn how to use it with some prospect of reasonable success. Even in quite simple cases, for a senior undergraduate course in Power Systems Analysis, there is just not sufficient time within the semester boundary to adequately address this problem. Experienced educators in the field would recognize that of the many difficulties surrounding the use of EMTP, the necessity of preparing 3-phase data for any given problem is paramount. Usually, students are familiar with one line diagrams which they use to solve many of the normal operating conditions of electric power networks. They are also familiar with symmetrical components and will recognize that there may have to be some accommodation to unbalanced conditions by the use of such techniques essentially using balanced networks to solve for specific but important fault conditions in a quasi steady state analysis. To alleviate this difficulty which exists in the Utility industry also, some years ago the author approached the Planning Department of Baltimore Gas and Electric with a proposal to write software that would allow a one line diagram to be the primary input to a somewhat constrained but widely applicable set of typical transient problems, mainly concerned with energization, fault clearing and capacitor switching. The intention was not so much as a permanent replacement for the direct use of EMTP, but rather a method of demonstrating the true power and universal use of EMTP to students and employees. The user of such sophisticated software as EMTP frequently experiences a discouraging period during the early learning which may result in long term reluctance to persevere with what could be ultimately turn out to be of great value. The use of the interactive packages which alleviate the necessity of introducing the 3-phase data are also efficient in instances in which several parts of a system are to be examined perhaps only superficially for early planning purposes.

Organization of Program

The organization of the program is basically defined as follows:

- Interface to EMTP (IFEMTP)
- Interactive Modifier (IAM)
- Database

In the interactive mode, the IAM prompts for a number of options as follows:

- Execute previously established case study
- Establish a new case study
- Modify existing case study
- Update database

For this purpose, a case study is defined as a one line diagram, with a previously established database. Establishing a new case study may involve actual changes to the input data to the interface or may mean changes only to the output form a previously executed interface case. The output from the interface program itself will be used as input data to the EMTP, but the IAM can interpose itself before EMTP is executed to modify the data so produced. An example of such an interposing operation would be siting of arresters. In general, the interface allows shunt elements, such a arresters, only as busbar connections defined by the one line diagram. In practice this would mean that arresters could only be placed on the station side of the transformer. The IAM allows the arrester to be moved to any point on the line or cable by means of a simple processor operating on the output data set of the interface before input to EMTP. A similar example would be the use of IAM to change the insertion resistance values of a breaker.

The majority of equipment met with in practice in Electrical Power Systems has been included in the program viz.:

- Overhead Transmission Lines, Underground Cables
- Transformers, Interbus Reactors
- Circuit Breakers
- Series Reactors and Capacitors
- Shunt Resistors, Reactors and Capacitors
- Single Line to Ground Faults
- Generators
- Switched Shunt Capacitors
- Pre-Insertion Resistors, Post-Extraction Resistors
- Surge Arresters

Input to the Interface (IFEMTP)

To initiate a case study of a transient on the system a set of records or card images must be placed in the input data set to the Interface. Further input to IFEMTP is required from the database containing the subtypes which are available. Messages from IFEMTP are provided on the monitor data set and the main output from the program, which will be input into the EMTP, is written once all the input data card images have been correctly read. The monitor data set which also includes program testing information, error messages and an acceptance message if the data is correct.

Before reading records, IFEMTP searches forward through the data set until a start record is found. Records will now be read until an end record is found. All records in between constitute an input data case study. Records with "/" in column 1 are treated as comment cards and are ignored. The first non-comment card after the initial record for this case is treated as a title record and will be reproduced on the output.

Every 3-phase connection should be specified including shunt equipment. However, each overhead line or underground cable is specified according to a record which includes breakers and transformers at both ends. (see Figure 1)

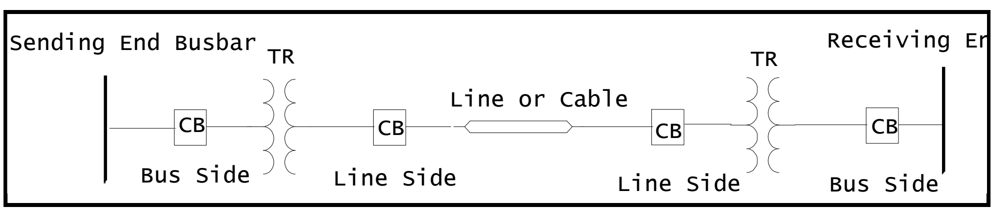

Figure 1 - Line Diagram for Overhead Transmission Lines and Underground Cables

All series elements, essentially only lines, cables and series reactors/ capacitors must specify a circuit number. (This must be unique to a line or cable but will be repeated for series reactors/capacitors.)

Shunt Element Values

While the usual method of including a shunt element is by reference to its subtype defined from columns 2 and 3 of the input data set and read from the database. An override of the subtype is possible where the actual values are known.

Establishment of Database

The database may be established for all device types and a few of each subtypes. The database consists of fixed blocked records, 80 bytes each and blocked at 4000 bytes/block (or 50 records per block). Device types and subtypes are in random order, the only restriction being that the parameter values for a particular device type and subtype follow immediately the identifying record for the device type and subtype.

The identifying records are always in columns 1-20 of the record and have "*" in column 1. The device types are as follows:

*OVERHEAD LINE
*UNDERGROUND CABLE
*TRANSFORMER
*CIRCUIT BREAKER
*FAULT
*GENERATOR
*SERIES REACTOR
*SHUNT RESISTOR
*SHUNT REACTOR
*SHUNT CAPACITOR
*SWITCHED CAPACITOR
*SURGE ARRESTER
*INTERBUS REACTOR

Overhead Lines (L)

The model used for this device type is the distributed model as described in Section 1.26 of the EMTP Rule Book [1]. The positive and zero sequence impedances are used and may be in various units as specified.

Underground Cables (U)

The model used for this device type could be the PI-equivalent as described in Section 1.23 of the EMTP Rule Book [1]. The coupling [R], [L], and [C] matrices are calculated from the manufacturer's data and follow standard rules.

Transformers

The model used for this device type is mostly the SATURABLE TRANSFORMER model as described in Section 1.25 of the EMTP Rule Book [1]. Generally assumptions have to be made about the saturable characteristic as the only data commonly available are the interwinding reactances. The bus side is always taken as the primary winding - this is a more fundamental distinction than sending/receiving end.

Circuit Breakers

The model used for this device type is the "ordinary switch" as described in Section 1.4 of the EMTP Rule Book [1]. It should be noted in passing that the Switch is actually modeled with small series resistance DR and shunt capacitance DC as shown in Figure 2. Both insertion resistance during energization and post-extraction resistance during clearing may be included and are defined within the database. (see Figure 3)

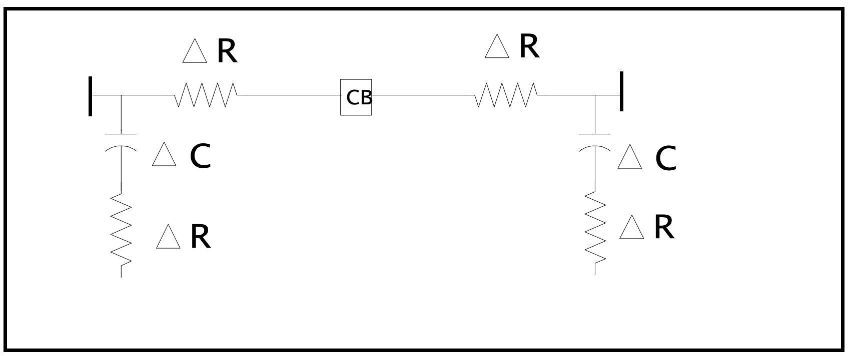

Figure 2 - Representation of Circuit Breaker

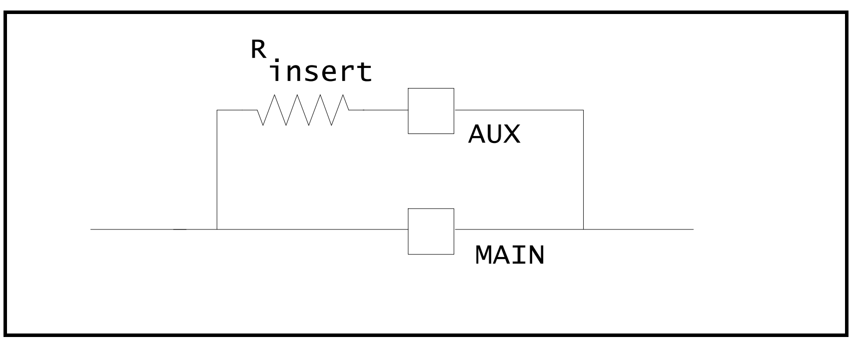

Figure 3 - Insertion Resistance Option

Faults (F)

The model used for this device type is a series combination of small resistance DR and circuit breaker closing to ground. Three-phase or single phase faults are the only types allowed presently. Any phase may be specified and, if the three-phase fault is employed, the three phases need not close at the same time.

Generators (G)

The model used for this device type is type 14 Sinusoidal function as described in Section 1.6 of the EMTP Rule Book [1]. The series reactance is read from the database according to the subtypes and the line voltage, phase advance angle with respect to the reference and the frequency along with the phase sequence are also obtained from the database.

Series Reactor (Z)

The model used for this device type is the series R-L-C branch as described in Section 1.21 of the EMTP Rule Book [1]. By suitable use of the subtypes it is possible to specify a series capacitor rather than series reactor since all three elements can be specified simultaneously. No switching of this element type is available.

Shunt Resistor (R)

The model used for this device type is the series R-L-C branch. Only resistance is possible and no switching is allowed.

Shunt Reactor (X)

The model used for this device type is the series R-L-C branch. Only reactance is possible and no switching is allowed.

Switched Capacitor/Inductor (A)

The model used for this device type is the series R-L-C branch in series with a switch. Any combination of the series R, L or C is allowed but at least one of them must be present. These values together with the switching times are provided by the subtype within the database.

Surge Arrester (S)

The model used for this device type is the ZnO Surge Arrester Model described in Section 1.32 of the EMTP Rule Book [1].

Future Developments

The interactive program described does not allow for graphical display other than the time graphs of these points in the system of interest for any given study. However, it is intended to use standard graphics packages to:

- draw the one-line diagram of the system under study
- invoke the modifiers by using menu selection from the screen
- allow changes of the system directly from the screen
- display maximum values, etc. on the system under study
- optimize arrester sittings
- determine worst-case closing sequences
- These operations will be implemented in the near future.

Acknowledgments

The author wishes to thank Mr. W.G. Thompson, Manager, Electric System Planning Department, Baltimore Gas & Electric Company for his interest and support in the work.

Reference

[1] EMTP Revised Rule Book Version 2.0, EPRI Research Project 2149-4, EL-6421-L, Vol. 1, Final Report, June 1989.

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Semiconverter Analysis

Operational and Harmonic Concerns Associated with a Semiconverter

Abstract

This paper clarified the harmonic problem associated with applications of a semiconverter. A comprehensive explanation of the harmonic generation and the analyses of converter operation with different firing angles were provided. Voltage and current waveforms showing the distortion characteristics of the input and output quantities are presented. The performance of an installed 2nd harmonic filter to reduce even harmonic injection into the system and to improve circuit power factor was evaluated using Electromagnetic Transient Program.

Introduction

A semiconverter, which is sometimes also referred to as a half-controlled three-phase bridge rectifier, is commonly adopted for industrial applications at power level up to several hundred kilowatts. The circuit configuration of interest is shown in Figure 1, where a semiconverter is supplied from a 480 V ac voltage source through a delta/wye connection isolation transformer. The load of the converter is represented by an RL series branch.

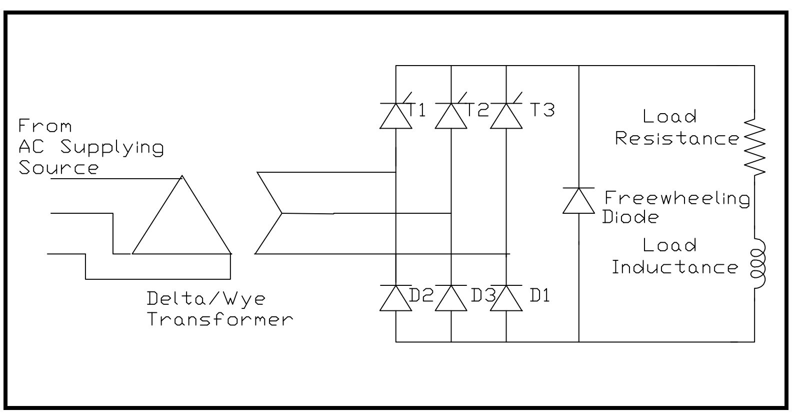


Figure 1 - AC to DC Conversion System Using A Semiconverter

Discussions of the semiconverter operation under idealized conditions can be found in power electronics texts[1][2][3]. Because only three control devices are used and because diodes are considerably less expensive than thyristors and do not need firing controls, the cost and complicity of the control circuitry of the semiconverter are greatly reduced if compared with a full controlled bridge converter. This makes the semiconverter vary attractive in applications where only one-quadrant operation (rectification) is required. Authors have noticed applications of the semiconverter for large ac generator excitor dc current supplies even in the power plants built in 90's.

While recognizing the advantages of the semiconverter, the problem associated with it should also be identified. The semiconverter could result in an injection of an excessive amount of even harmonics into the ac supplying system, particularly when the converter is operated with a large firing angle and the freewheeling diode of the converter carries a significant current. A characteristic which helps to distinct the harmonic distortion caused by the semiconverter from those resulting from other types of power electronics conversions is a pronounced waveform unsymmetry of the ac line current with respect to the current zero level. The frequency spectrum of the current under such conditions contains rich even harmonics. A pair of typical voltage and current waveforms (computer simulation) from a semiconverter application are given in Figure 2 and Figure 3, to illustrate the discussed waveform distortions.

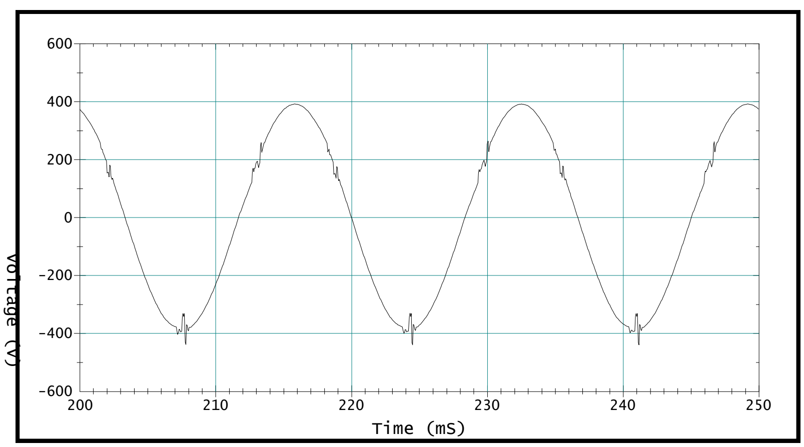


Figure 2 - Waveform of Line-to-Ground Voltage

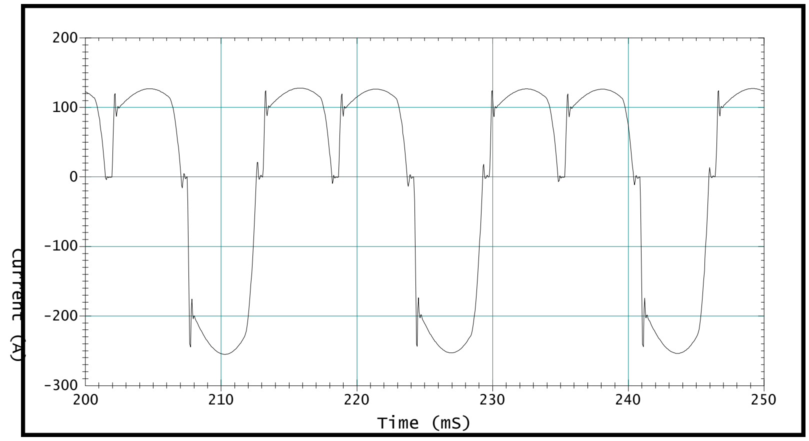


Figure 3 - Waveform of Line Current

These waveforms were measured from the ac supplying side of the isolation transformer. The voltage waveform clearly indicates a three-pulse operation and the current waveform shows a dramatic unsymmetry with rich even harmonic contents.

Although similar waveforms have been frequently observed in practices, because of a lack of published information regarding this issue, the formation of the problem has not been comprehensively understood by many electrical engineers who work at the front line of industries and electric utilities. The objective of this paper is to provide a clear explanation of the operation principle of the semiconverter, to illustrate its performance characteristics, and to demonstrate a approach which can be used to reduce the current distortion seen by the supplying ac network.

Operating Principle

A semiconverter can be considered as a series combination of phase-controlled half-wave converter (the upper bridge) and a uncontrolled half-wave rectifier (the lower bridge). Apparently, if the upper bridge thyristors are fired at natural commutation points, the semiconverter operates exactly as a full-wave diode bridge rectifier. The EMTP simulated ac line-to-neutral voltage (Va), the ac line input current (Ia), the dc output voltage (Vdc) and the dc load current (Idc) for the system shown in Figure 1 under such firing condition are given in Figure 4.

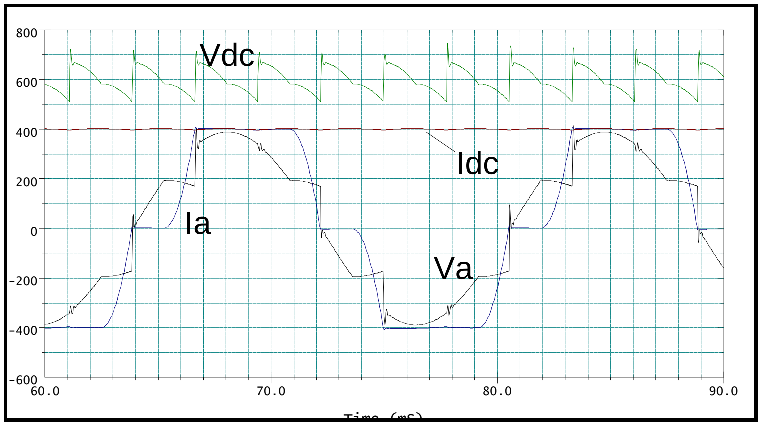


Figure 4 - Input/Output Quantities of Six-Pulse Operation

The transformer primary line-to-line voltage is 480 V_{rms} and the ratio of the delta/wye connected isolation transformer is 1 : 1. Consequently, the line-to-neutral peak voltage of the wye-connected secondary is 392V_p. The load of the converter consists of 1.5 Ω resistance in series with 10 mH inductance. In the simulation, properly sized source and transformer impedances as well as carefully selected snubber circuits were used. These factors are responsible for the voltage disturbance around each commutation point. Therefore, instead of seeing six π/6 radian arcs, six triangulated ripples are observed in each power frequency cycle. Because of the impedance of the supplying system, the phase current commutation is completed with a finite period of time instead of jumping from zero to the full load level as under an ideal circuit condition. The symmetry between three phase currents and the symmetry of each individual phase current with respect to the voltage zero crossing points prevent any triplen and even harmonics appearing in the ac line current[2][3][4] under this operation condition.

When the thyristors are fired with a time delay, the converter can have two basic operation modes. Because the lower bridge is completely uncontrolled and it always acts as a half wave diode rectifier. The operation mode of the semiconverter depends only on the firing control of the upper bridge. Before the delaying angle reaching π/3 degrees, the converter is in a six-pulse operation mode. After the delaying angle reaching and exceeding π/3, the converter starts and keeps the three-pulse operation mode. The transition from the six-pulse operation to the three-pulse operation is gradually completed as a firing angle increasing from 0 to 60 degrees. The waveforms of the dc output voltage with 0, 30, and 60 degree firing angles presented in Figures 5, 6 and 7 respectively illustrate this transition.

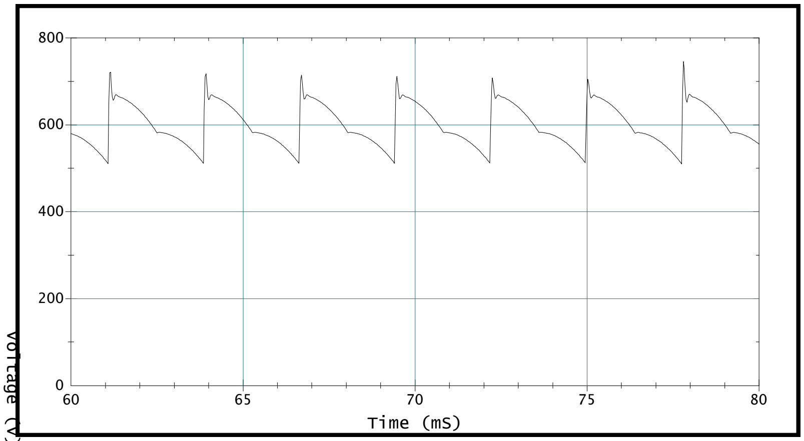


Figure 5 - Firing Angle = 0 Deg.

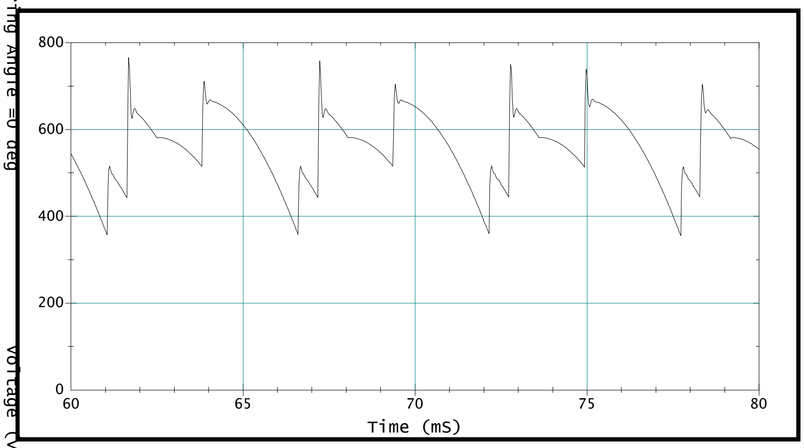


Figure 6 - Firing Angle = 30 Deg.

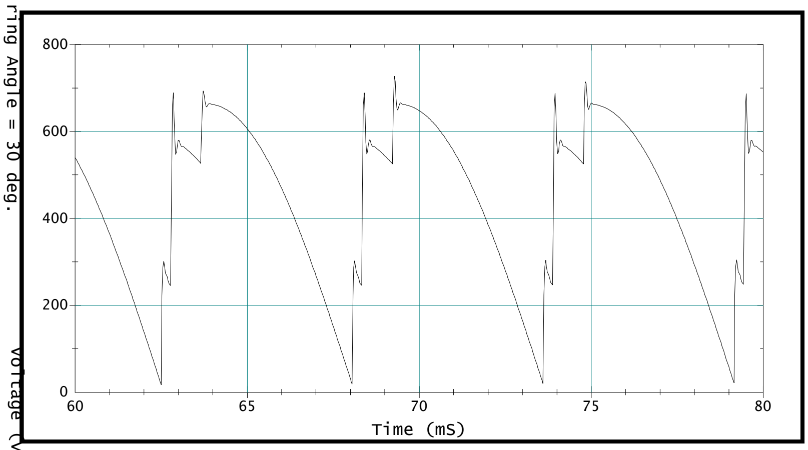


Figure 7 - Firing Angle = 60 Deg.

The formation of a dc output voltage wave shape can be more clearly explained with the help of the graphic illustration of Figure 8.

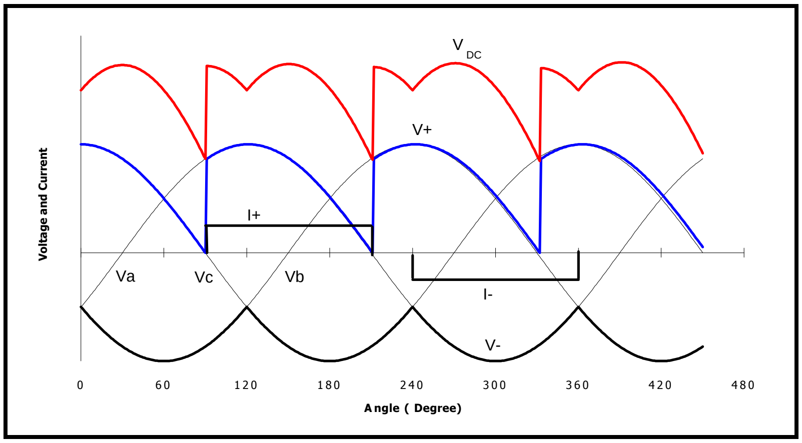


Figure 8 - Formation of DC Output Voltage of Semiconverter

In Figure 8, three phase line-to-neutral voltages are shown. Because of no control on the lower bridge of the converter, the changing of the potential of the common anode of the diodes (negative dc pole V-) always follows the bottom envelop of the line-to-neutral voltages of the three phases. For the upper bridge, the potential of the common cathode of the thyristors (positive dc pole V+) is controlled with the firing angle.

Theoretically, the thyristors can be fired at any delaying angle α between 0 and 180 degrees. Namely, for the thyristor T1 of the phase a, the conducting can happen anywhere between the commutation point of T3 and T1 (positive Vc and Va intersection) and the commutation point of D1 and D2 (negative Vc and Va intersection). As T1 conducting, the potential of the positive dc pole is the same as the potential of the transformer terminal of the phase a. The output voltage of the converter (Vdc) is the difference between the top envelop, consisting of the segments of the phase-to-neutral voltages corresponding to the conducting period of each phase thyristor, and the bottom envelop of the line-to-neutral voltages. Figure 8 illustrate formation of the dc output voltage waveform and the ac line input current waveform with a 30 degree firing angle. The difference noticed between this dc voltage waveform and that given in Figure 6 is due to the inclusion of practical considerations in the simulation. Apparently, for a balanced three-phase system, the maximum conducting period of each thyristor is 120 degrees. Note that if a firing angle is smaller than 60 degrees or if the converter operates in the six-pulse mode, the output voltage is a continued curve. The thyristor or diode of each phase conducts for a fixed period of 120 degrees. Therefore, the output current is continued and the freewheeling diode connected across the dc positive and negative buses carries no current and plays no role in the circuit operation.

The waveforms of phase a input current of the converter corresponding to 0, 30, and 60 degree firing angles are given in Figure 9. To illustrate the current starting and ending points moving with respect to the voltage of the phase, the waveform of the phase a line-to-neutral voltage is plotted in the same figure. This voltage waveform corresponds to the converter firing at 60 degrees.

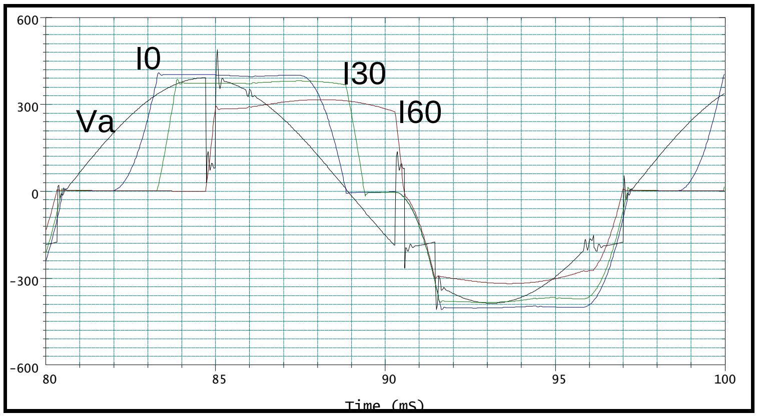


Figure 9 - Waveforms of Phase A Current with α=0, 30, And 60 and Phase A Voltage with α=60.

Figure 9 indicates that when the converter firing angle increases from 0 to 60 degrees, in additional to the current magnitude reduction, only the starting and ending points of the positive conduction period are deferred correspondingly. The starting and ending points of the negative conduction period remains unmoved. When the firing delay gets beyond 60 degrees, the converter operates with the three-pulse mode and the output voltage becomes discontinued. The Figure 10 shows the output voltage waveforms for the operations with the firing angle equal of 90, 120, and 150 degrees respectively.

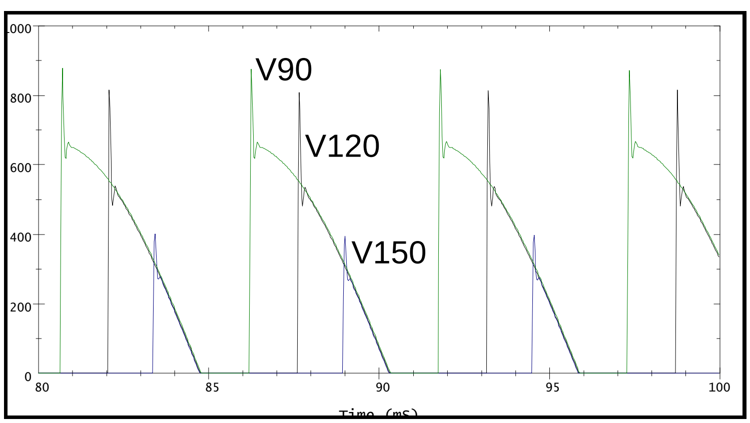


Figure 10 - Waveforms of Output Voltage With Firing Angle = 90, 120, and 150 degrees.

In fact, when the delay angle becomes greater than 90 degrees, the phase-controlled upper bridge half-wave converter starts to act as an inverter. Namely, its contribution to the output voltage becomes negative. With the ideal voltage waveforms shown in Figure 8, considering the semiconverter as the series connection of a uncontrolled half wave rectifier with a phase controlled half wave converter, the average dc output voltage can be expressed as the summation of two parts[2].

$$V_d = \frac{3\sqrt{6}}{2p} V_f (1 + \cos a)$$

Where the constant term is the contribution of the uncontrolled half-wave rectifier and the α dependent term is the contribution of the phase-controlled half-wave converter. As shown by Figures 5, 6, 7, and 10 and indicated by the above voltage expression, when the firing angle increases from 0 to 180 degrees, the average output voltage decreased from the maximum to zero. The spikes appearing at the front edges of the voltage pulses reflect transients caused by simulated power electronic switching. This type of overshooting can be controlled by adjusting parameters of the snubber circuit.

A distinctive remark of the three-pulse operation is that the ending points of the phase conduction on both positive and on negative current flowing directions are fixed. As a result, a further firing delay beyond 60 degrees makes the thyristor and diode of each phase carry current for a period of less than 120 degrees. The current waveforms resulting from 90, 120, and 150 degree firing delay are shown in Figure 11.

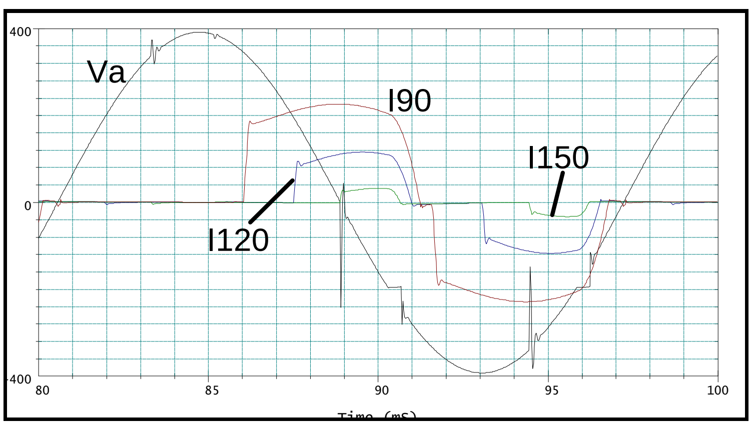


Figure 11 - Waveforms of Input Currents with a= 90, 120, 150 Deg. and of Input Voltage with a=150 Deg.

To supply an inductive load, the freewheeling diode now must come to action and to provide the load current path. Otherwise, the thyristors will fail to cease conducting at specified places.

Figure 12 illustrate the relations between the semiconverter input current, the load current, and the current flowing through the freewheeling diode while firing was delayed by 90 degree.

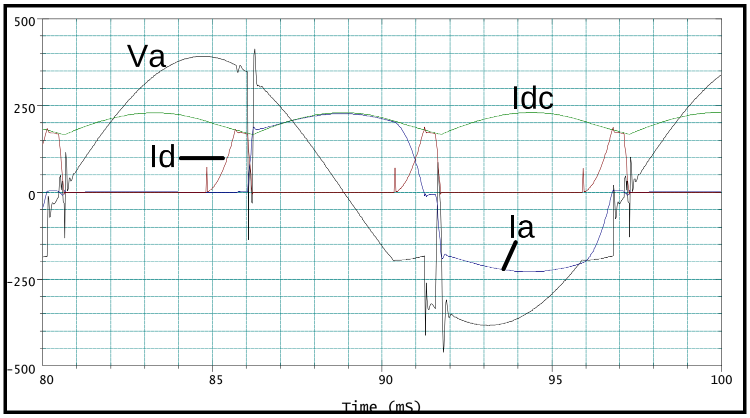


Figure 12 - Phase A Voltage, Input Current, Output Current And Freewheeling Diode Current

Harmonic Characteristics

It is clear that, regardless firing angle, the mechanism of the semiconverter operation does not create a unsymmetry of the line current with respect to the current zero level. This means that the semiconverter does not generate a dc component of the input current. However, as being illustrated, for any non-zero firing delay, the line current waveform is unsymmetrical with respect to the voltage zero crossing of the phase voltage. The degree of the unsymmetry changes with the firing angle. Although the balance of three phase still prevents generation of any triplen harmonics, this unsymmetry does create a series of even harmonics. The current waveforms for firing angle smaller than and equal to 60 degrees and the waveforms for firing angle greater than 60 degrees can be classified into two basic patterns as previously shown in Figure 9 and Figure 11 respectively.

If the current waveforms are idealized, the pattern shown in Figure 9 should consist of the 120 degree movable positive current pulse and the 120 degree standstill negative current pulse. The pattern shown in Figure 11 has the pulse width of the both positive and negative pulse varied with the firing angle. But, the conduction pulses of either polarity end at the natural commutation points. Although these two described conduction patterns are different, it was found that the Fourier expansions for these two current patterns have the same sets of Fourier coefficients. Therefore, the input line current can be written as

$$i(t) = \sum_{1}^{\infty} a_n \cos n\omega t + \sum_{1}^{\infty} b_n \sin n\omega t, \text{ Eq. 1}$$

where

$$a_n = \frac{1}{\pi}\int_0^{2\pi} I_{dc} \cos(n\omega t) d(\omega t)$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} I_{dc} \sin(n\omega t) d(\omega t)$$

for n=1, 2, 3, ...

Derived from these integrals, the coefficients for the current Fourier expansion obtained are

$$a_{n=2m} = \frac{2I_{dc}}{n\pi}\sin(n\frac{\pi}{6})(1-\cos n\alpha), \text{ Eq. 2}$$

$$b_{n=2m} = \frac{-2I_{dc}}{n\pi}\sin(n\frac{\pi}{6})\sin(n\alpha), \text{ Eq. 3}$$

for n = 2, 4, 6, ...

$$a_{n=2m+1} = \frac{-2I_{dc}}{n\pi}\cos(n\frac{\pi}{6})\sin(n\alpha), \text{ Eq. 4}$$

$$b_{n=2m+1} = \frac{2I_{dc}}{n\pi}\cos(n\frac{\pi}{6})[1+\cos(n\alpha)], \text{ Eq. 5}$$

for n = 1, 3, 5, ...

These Fourier coefficients indicate that the semiconverter does not generate any triplen harmonic as far as a balance of the three-phase system is maintained. However, the even harmonic generation is the inherent characteristic of the semiconverter.

The Eq. 2 and Eq. 3 can be combined to obtain the magnitude of an even harmonic as expressed in Eq. 6.

$$\begin{aligned} \left|C_{n=2m}\right| &= \sqrt{a_n^2 + b_n^2} \\ &= \frac{2\sqrt{2}I_{dc}}{n\pi}\sin(n\frac{\pi}{6})\sqrt{1-\cos(n\alpha)} \end{aligned} \quad \text{Eq. 6}$$

for n = 2, 4, 6, ...

This expression reveals that an even harmonic current component reaches its maximum when $n\alpha = 180$ degrees. Therefore, the peak of the 2nd is expected at

90 degrees and the two peaks of the 4th harmonics are expected at 45 and 135 degrees respectively with maximum magnitudes of approximately 55% and 28% of the dc load current I_{dc}.

In order to provide a more vivid illustration of harmonic variation with firing angle, an EMTP model of the circuit shown in Figure 1 was used to simulate the operation of the semiconverter with the firing angle linearly increased from 0 to 165 degrees. The obtained line current waveforms on the transformer secondary are presented in Figure 13.

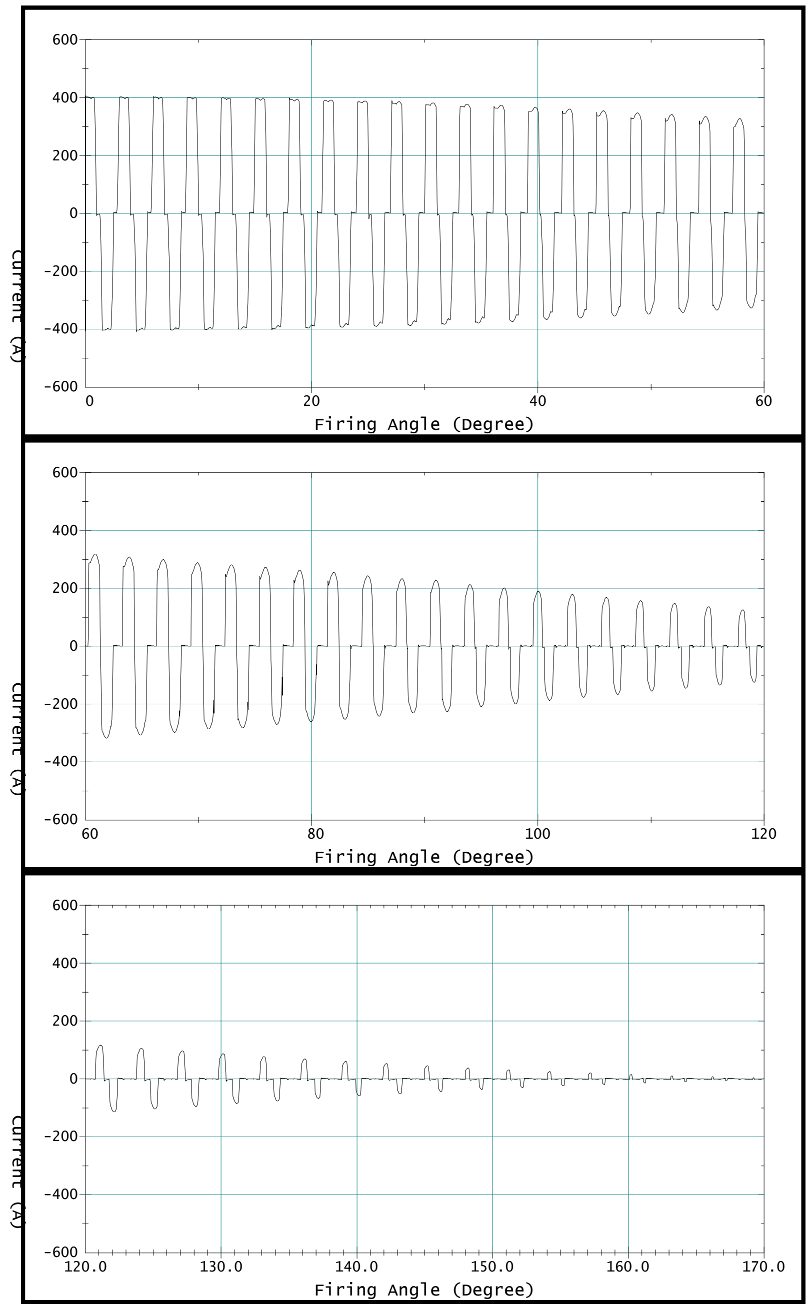
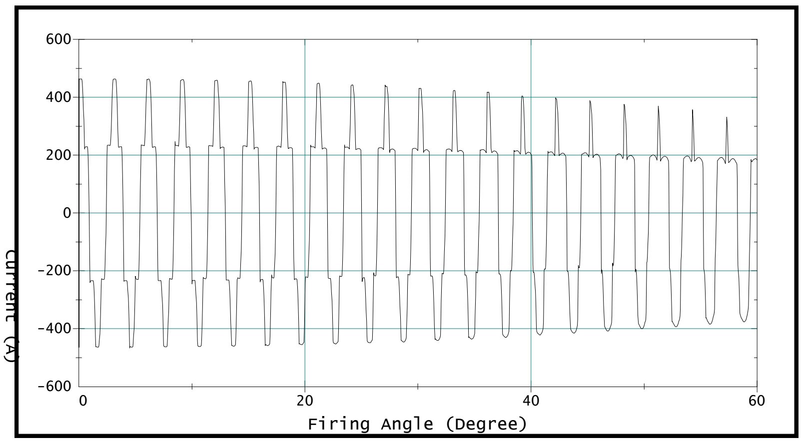
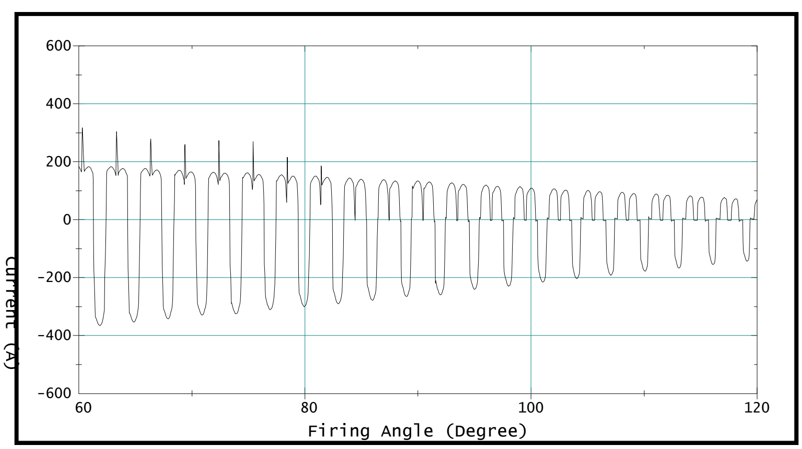


Figure 13 - Line Current Waveform of Wye-Winding Side

In Figure 13, the horizontal axis marked the degrees of the firing angle. To emphasize the current magnitude changes with the firing angle at the same time of waveform changing, the magnitude scale of the current for the three different ranges of firing angle are selected to be equal.

Because of the line current appearing on the delta-connected transformer primary is simply the result of subtraction of the two corresponding line currents of the secondary, the primary current shows double humps on one side and a single hump with twice magnitude on the other side. The changing waveform of this current with the firing angle is illustrated in Figure 14. Although the primary current waveform seems displaying a greater unsymmetry than that of the secondary current, even harmonic contents of the primary current are the same as that of the secondary current.





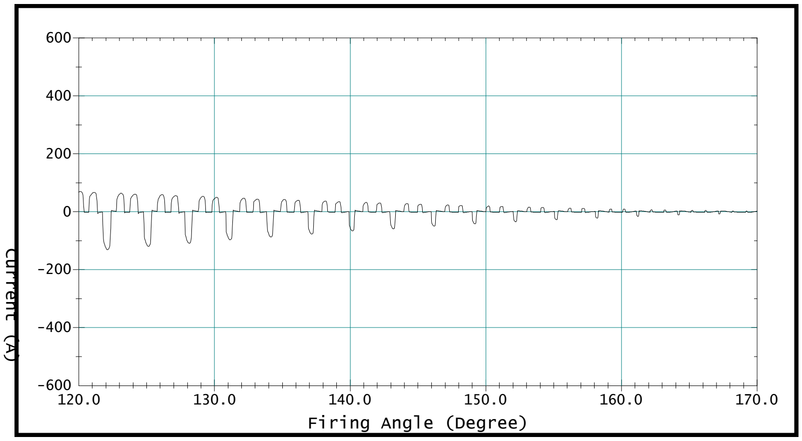


Figure 14 - Line Current Waveform of Delta-Winding Side

The curves given in Figure 15 illustrate the trends of the most important even harmonics within a complete range of the firing delay.

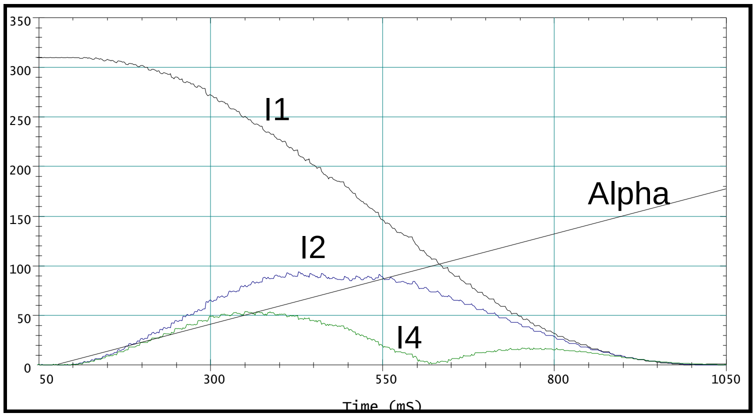


Figure 15 - Fundamental and Even Harmonics and Firing Angle.

Note that because of the existence of the source impedance, the practical commutation have made the simulated current pulses differ from perfect square waves, which were assumed for simplifying theoretical derivations. As a consequence, the harmonic peaks obtained from the simulation were shifted from the places determined according to the Eq. 6.

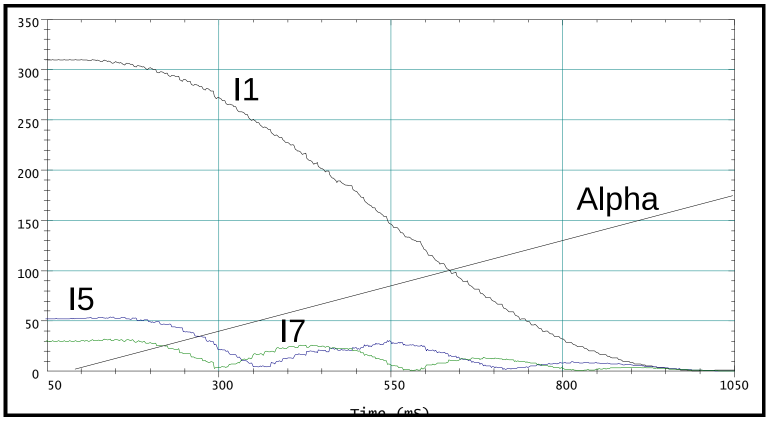
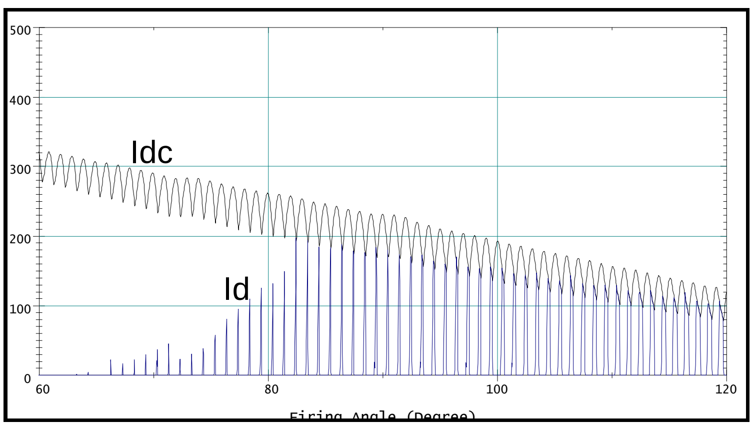


Figure 16 Firing Angle and Fundamental, 5th, and 7th Harmonics of Semiconverter Current

Figure 16 illustrate changing of 5th and 7th harmonics with the firing angle variation. Comparing Figure 15 with Figure 16, it is realized that in a practical operation range of time delay, the magnitude of the 2nd harmonic is about 2 to 3 times of that of the 5th harmonic. Therefore, for a semiconverter, the most concerned harmonics are low order even harmonics.

As previously mentioned, for an inductive load, the freewheeling diode carries current during an interval in which the out-going thyristor has stopped conducting and the in-coming thyristor has not been fired.



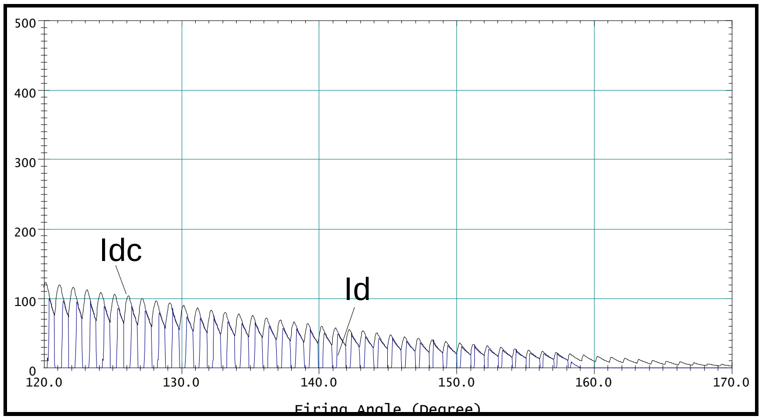


Figure 17 - Current through Freewheeling Diode.

The freewheeling diode current and the load current for a firing angle between 60 and 170 degrees are plotted in Figure 17. The freewheeling diode conducting interval increases with the firing angle. The magnitude of the current reaches the peak around 90 degrees. If the freewheeling diode is not connected, the load current will force the outgoing thyristor maintaining conducting until the in-coming thyristor is fired. This results in a power factor decreasing.

Harmonic Reduction & Power Factor Correction

Although a power factor problem associated with the semiconverter application has not been discussed in detail in this paper, it can be logically deducted that the power factor associated with the application is a function of the firing angle and tends to get low when the firing angle increases. The statement is supported by the fact that the line current is getting out-of-phase with respect to the voltage as the firing angle increases.

A perspective approach which can benefit both the power factor correction and the harmonic reduction is to install a capacitor bank as a tuned filter at the converter input terminals. Usually, filter installations for each and every important harmonic components are practically unacceptable because of the cost consideration. Therefore, the recommended practice is to install a single second harmonic filter with relatively large capacity.

The EMTP simulation has been conducted to investigate the effectiveness of the proposed solution. For the converter with a dc output rating of 260 kW, a three-phase filter of 250 kVAr is connected on the transformer secondary. The waveforms of the phase voltage and the input current of the transformer primary obtained from the simulation with the worst firing angle of 90 degrees are presented in Figure 18.

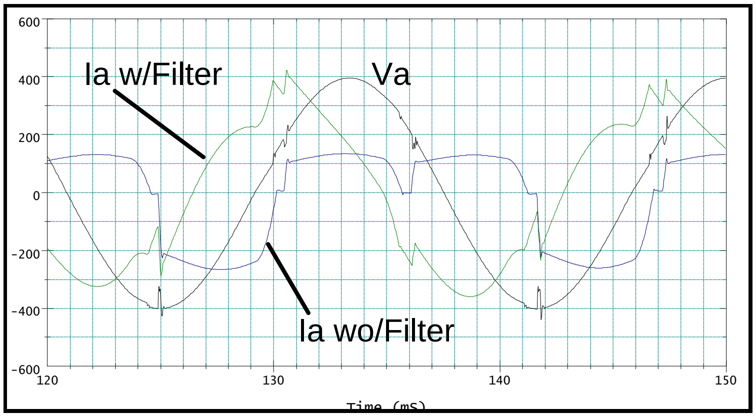


Figure 18 - Phase Voltage and Current Waveforms With and without Filter

To illustrate the improved power factor, the current waveform without the filter has also been given in Figure 18. It is clear that the capacitor compensation has made the line current change from significantly lagging to significantly leading.

The harmonic filtering effects are shown with the bar chart given in Figure 19. After the 2nd harmonic filter connection, the fundamental component of the current has increased by approximately 85% and the magnitude of the second harmonic has been reduced to the 18 percent of the original. The magnitudes of the 4th and 5th harmonics are also slightly reduced. As consequence, the Total Harmonic Distortion (THD) of the line current is reduced from 70.6% to 13.7%.

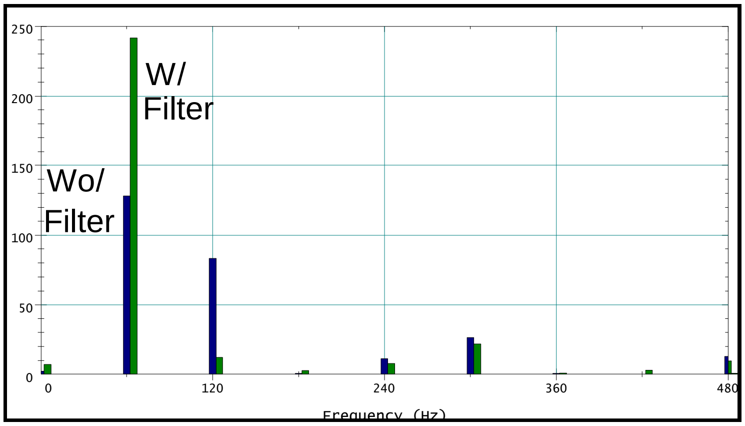


Figure 19 - Comparison between Current Spectrums Obtained with and Without 2nd Harmonic Filter

Conclusions

A semiconverter has two operation modes. As a firing angle increasing from 0 to 60 degrees, the converter changing from the six-pulse operation into the three-pulse operation. With a further increased firing angle beyond 60 degrees, the converter is always in three-phase operation mode with the increased input current and output voltage discontinuity.

The even harmonic generation is the inherent characteristic of the semiconverter. The worst even harmonic peak occurs when the firing angle is around 90 degrees.

The power factor of the semiconverter varies with the firing angle. In a range of practical firing delay, the power factor is poor and decreases with the firing angle increases.

A capacitor bank tuned as a second harmonic filter can effectively reduce even harmonic injections into the ac supplying system and it can greatly help to improve the circuit power factor.

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Power Line Conditioner Analysis

An Analysis of Active Power Line Conditioners Using the Electromagnetic Transients Program

Abstract

The availability of relatively low cost, high-power semiconductor devices has stimulated interest and research on the use of active power line conditioners as practical solutions in reducing harmonic distortions in electric power distribution systems. Several prototypes have already been reported in the literature with applications specific to distribution systems. This paper describes how the Electromagnetic Transients Program (EMTP) can be used as a tool to evaluate the effectiveness of active power line conditioners (APLC) to reduce harmonic distortion in distribution systems. The system under study consists of a three-phase diode bridge rectifier served by three single-phase distribution transformers. A shunt APLC and/or shunt passive power filters (PPFs) are used to reduce harmonic distortion. Special attention is given to the shunt APLC rating when used together with shunt PPFs for harmonic distortion reduction.

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editors note:

The article dealing with ASD Motor Transients will be published in the next issue of EMTP Tech Notes. If you would like to discuss this problem, feel free to call Chris Melhorn at (615) 675-1500 x 23.