HARMONIC TRANSFER AND POWER COMPONENTS IN THE AC/DC CONVERTER

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Abstract – **The purpose of this work is to investigate the harmonic transfer in the 3-phase AC/DC converter in terms of the behavior of its power components, verifying the influence of the voltage distortion on AC subsystem power components. The digital computer simulation of the AC/DC converter behavior on optics from harmonic interaction between the converter and the power system is a flexible and useful tool to its objective. For that, the new methodology for nonlinear electric circuits analysis proposal in [4], applied to get AC/DC converter steady-state response, and Czarnecki's power definition are used.**

I. INTRODUCTION

Due to the crescent proliferation of nonlinear loads, mainly the power electronic loads, the electric power systems are gradually receiving big injections of harmonic currents that provoke, among other effects, voltage distortion. So, the voltages and/or currents of these systems let their sinusoidal wave-forms, or for they shall be supplied by a nonsinusoidal voltage, or for the load presenting nonlinear elements, or with time - variant parameters.

Among the several proposed power component definitions proposals to electric circuits operating in nonsinusoidal conditions, presented by Czarnecki [1][2] show mathematical and physically coherent, as with them, it is possible to understand the physical properties from the powers on the nonlinear circuits , as well as, project compensators for reduction from non-active power, improving the energy use from these circuits. For those reasons , it is adopted this set of power components definitions to electric circuits operating in nonsinusoidal conditions , which is here mentioned as analysis tool of the harmonic interactions (harmonic transfer in AC/DC converters).

II. HARMONIC TRANSFER IN AC/DC CONVERTER

The problem of harmonic interaction in AC/DC converters aims to answer how the voltage or current harmonics generated by the converter or presents on AC voltage source that supply by the converter are transferred of the AC side to CC side and vice-versa, as well as to describe the relation among frequencies and symmetrical components when the harmonics are transferred through the converters.

Y. Jiang and A. Ekström [3] established the rules which govern the harmonic frequencies transfer into the AC/DC converter, up Fourier´s analysis on the switches functions, binary signals that represent the operation conditions of the AC/DC converter, turning them to the space vector ab.

III. CZARNECKI´S POWER COMPONENTS DEFINITIONS

It is showed in [2] that the load current on a asymmetrical electric circuit with nonlinear load and/or time-variant may be decomposed into five mutually orthogonal current components. Then,

$$\|\bar{i}\|^2 = \|\bar{i}_a\|^2 + \|\bar{i}_r\|^2 + \|\bar{i}_u\|^2 + \|\bar{i}_s\|^2 + \|\bar{i}_h\|^2 \quad \text{(III.1)}$$

With $\bar{i}$ being the load current, $\bar{i}_a$ the active current, $\bar{i}_r$ the reactive current, $\bar{i}_u$ the unbalance current, $\bar{i}_s$ the displacement current and $\bar{i}_h$ the harmonic current.

This equation explains five different reasons for to the increasing of the rms source current value from 3-phase circuit : the power active of transmission -$\bar{i}_a$; the oscillating energy flow - $\bar{i}_r$; the unbalance of load - $\bar{i}_u$; the shift load conductance with the frequency - $\bar{i}_s$ and the harmonic generation by nonlinearity and/or load time-variation parameters.

The power equation base on Czarnecki´s current decomposition analysis is:

$$S^2 = P^2 + Q^2 + D_u^2 + D_s^2 + D_h^2 \,, \quad \text{(III.2)}$$

IV. CASE STUDIES

With the aim of investigating the harmonic transfer through the AC/DC converter in terms of the behavior of its power components , the harmonic transfer rules, described in section II , and the definitions concerned Czarnecki´s power components, showed in the previous section are illustrated in case studies which the converter is supplied by balanced and symmetrical sinusoidal or nonsinusoidal voltage source.

The observation of the power components behavior is done based on the reference the 6 or 12 pulses AC/DC converter, supplied by balanced and symmetrical sinusoidal voltage source. From this basic case, others are built by the distortion voltage source, joined to a single balanced and symmetrical harmonic component, with integer multiple frequency from fundamental, with amplitude which is a percentile of the component fundamental amplitude. This chosen criteria allows the observation of the power components behavior in relation to only one given harmonic that can be characteristic or non-characteristic, of positive, negative or zero s equence, as well as in relation to the percentage distortion variation.

The cases in study are defined as follow: Basic Case (balanced sinusoidal voltage source); Case I (balanced sinusoidal voltage source, with positive sequence characteristic harmonic); Case II (balanced sinusoidal voltage source, with negative sequence characteristic harmonic); Case III (balanced sinusoidal voltage source, with positive sequence non-characteristic harmonic); Case IV (balanced sinusoidal voltage source, with negative sequence non-characteristic harmonic); Case V (balanced sinusoidal voltage source, with zero sequence non-characteristic harmonic).

In all those cases the following operation conditions are studied: Converter operating with constant CC current(active current constant control system); fire angle scan with constant CC power.

IV.1 CC CURRENT CONSTANT - 6 PULSE AC/DC CONVERTER

The Basic, I, II, III, IV and V Cases survey is done with the obtained from steady-state response of the converter , by using the developed technique in [4] and presented in [5][6][7][8], supplied by balanced sinusoidal voltage source, to the Basic Case, and balanced distorted (nonsinusoidal) voltage source with 7^{th} harmonic order (characteristic and positive sequence), 5^{th} (characteristic and negative sequence), 4^{th} (non-characteristic and positive sequence), 2^{th} (non-characteristic and negative sequence) and 3^{th} (non-characteristic and zero sequence), to the I, II, III, IV, and V Cases, respectively. In those last cases , each harmonic component is applied separately to distort the voltage source, into three percentages of distortion (1, 5 and 10%).

With the voltages and currents source, the AC subsystem power components are calculated and presented in tables , along with the percentage variation $(\ \%)$ of those powers in relation to the Basic Case. As additional element of analysis, the CC voltage, CC current and valves fire angle average values are included on the tables.

The Tables IV.1, IV.2 and IV.3 (last page) show the results to the Cases I (7^{th} harmonic), III (4^{th} harmonic) and V (3^{th} harmonic) power components.

IV.2 FIRE ANGLE SCAN AND CC POWER CONSTANT – 6 PULSE AC/DC CONVERTER

The harmonic transfer into the AC/DC converter is here observed through its power components behavior, on the AC subsystem, varying the valve fire angle from zero to 30 degrees and keeping the CC power constant. Comparisons are made of the rack within the sinusoidal Basic Case with the outcomes from the Cases I, II, III, IV and V previously defined. All the cases are calculated with distortion percentage of 10%.

The Figures IV.1, IV.2, IV.3 and IV.4 show the results obtained for power components D_h (cases I and II), Q (Cases III and IV) and P and Q (Case V), respectively.

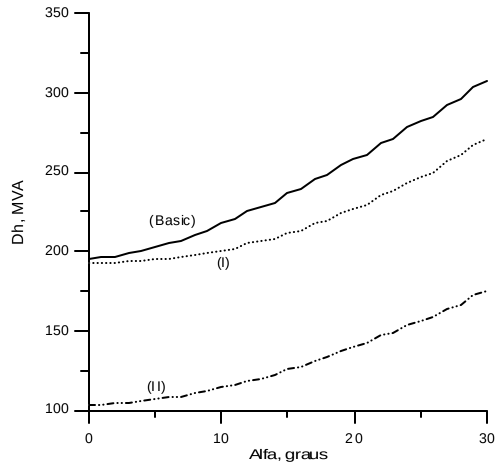

Figure IV.1: Harmonic Power(D_h); Basic Case, I (h=7) and II (h=5).

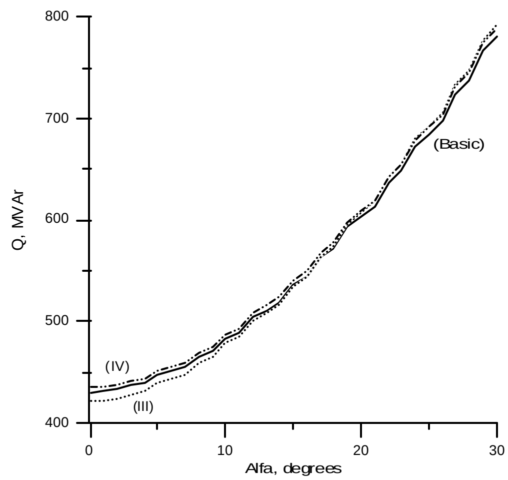

Figure IV.2: Reactive Power(Q); Basic Case, III (h=4) and IV (h=2).

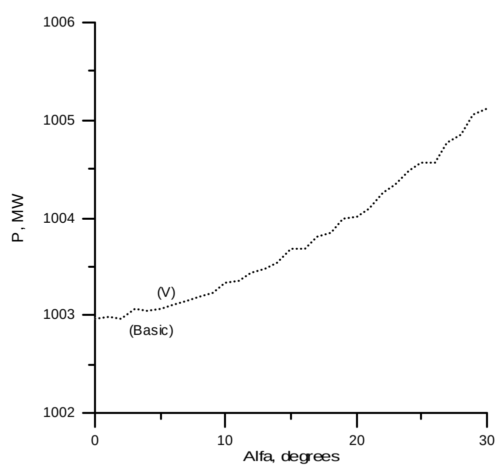

Figure IV.3: Active Power(P); Basic Case and V (h=3).

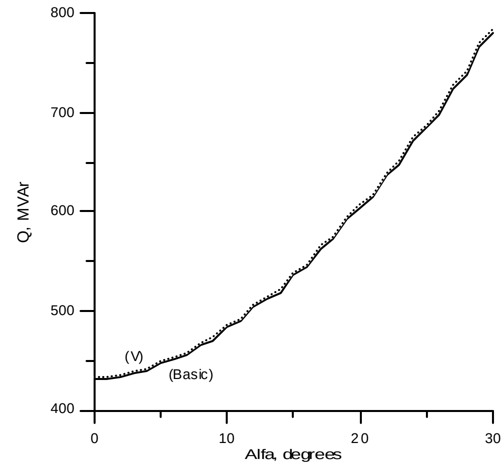

Figure IV.4: Reactive Power(Q); Basic Case and V (h=3).

V. RESULT DISCUSSIONS

Some of the drawn conclusions based on this analysis are : in CC current constant 6-pulse AC/DC converter, the AC subsystem active power P is practically constant, indicating the action of the control; being P the principal component from power S, this one does not vary so much, which makes the FP of the AC subsystem to present little variation; consequently, the effect from harmonic distortion outcomes on the other AC subsystems power components (Q, D_s, D_h); the D_u power presents little influence on S composition due the balanced converter. Their few values outcomes from the tiny unbalanced into the thyristor trigger; the reactive power Q of the AC subsystem suffers more variations on the cases that the distortion is aggravated by characteristics harmonics (cases I and II). In those situations, the voltage distortion provokes an increase of the angular shift between the harmonics voltages and currents of the AC side converter and occurs the increase of the rms value of them, with the consequent elevation from reactive power Q. On the cases of no- characteristics harmonics distortion (cases III, IV and V), this shift does not increase significantly, reflecting on small elevation from this power; characteristics harmonics, of positive or negative sequence, distorting the source voltage decrease the harmonic power D_h, as the order from harmonic present on voltage lets of being computed into the calculation of the generated harmonic current i_h; the distortion voltage source caused by 3th harmonic does not change significantly the converter way. This harmonic is not transferred CC side and the powers do not suffer significant changes in relation to the Basic Case. This fact can be explained by the converter impedance increase in that frequency, avoiding its transfer to CC side.

On a general way, the source voltage distortion for characteristics harmonics, of positive or negative sequence , influences more significantly the power components , mainly the reactive power Q.

VI. CONCLUSIONS

The purpose of this work is to investigate the harmonic transfer in the 3-phase AC/DC converter in terms of the behavior of its power components, verifying the influence of the voltage distortion on AC subsystem power components.

A new paradigm of power systems analysis must be incorporated by power engineers. Different phenomena are involved when those systems are submitted on nonsinusoidal voltages and/or currents. The harmonic transfer (harmonic interaction) into the AC/DC converter and the power components in those nonsinusoidal systems are clear examples.

The conjugate analysis of this phenomena with the observation from the power components on harmonic transfer into the AC/DC converter, even in particular case studies, shows the possibility from apprehension by one typical phenomenon of study from electronic can be done by sedimentary power engineers daily language what is the power electric.

VII. REFERENCES

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Table IV.1: Case I Power Components (h=7).

	p=1%	D%	p=5%	D%	p=10%	D%
$S_{(AC)}$	1171,77 MVA	+0,45	1175,10 MVA	+0,73	1178,10 MVA	+0,99
$P_{(AC)}$	1014,88 MW	+0,45	1015,63 MW	+0,52	1012,87 MW	+0,25
$Q_{(AC)}$	538,53 Mvar	+0,95	548,97 Mvar	+2,91	561,74 Mvar	+5,31
$D_{u\,(AC)}$	1,03 MVA	-68,89	3,21 MVA	-3,64	2,84 MVA	-14,68
$D_{s\,(AC)}$	99,45 MVA	-	59,32 MVA	-	9,57 MVA	-
$D_{h\,(AC)}$	207,74 MVA	-11,75	210,85 MVA	-10,44	215,33 MVA	-8,53
$FP_{(AC)}$	0,8661	0,00	0,8643	-0,21	0,8597	-0,73
V_{CC}	505,01 kV	+0,01	505,02 kV	+0,01	504,99 kV	+0,01
I_{CC}	2,0025 kA	+0,13	2,0036 kA	+0,18	1,9979 kA	-0,11
a_{CC}	14,17°	+0,49	14,63°	+3,75	16,01°	+13,58

Obs. : (AC) AC Subsystem; CC Average Value.

Table IV.2: Case III Power Components (h=4).

	p=1%	D%	p=5%	D%	p=10%	D%
$S_{(AC)}$	1166,74 MVA	+0,01	1170,64 MVA	+0,35	1176,32 MVA	+0,84
$P_{(AC)}$	1010,47 MW	+0,01	1012,75 MW	+0,24	1013,88 MW	+0,35
$Q_{(AC)}$	533,55 Mvar	+0,01	535,04 Mvar	+0,30	536,93 Mvar	+0,65
$D_{u\,(AC)}$	3,33 MVA	-0,09	1,88 MVA	-43,51	1,98 MVA	-40,34
$D_{s\,(AC)}$	10,59 MVA	-	53,27 MVA	-	106,85 MVA	-
$D_{h\,(AC)}$	235,40 MVA	-0,01	235,84 MVA	+0,18	236,77 MVA	+0,57
$FP_{(AC)}$	0,8661	0,00	0,8651	-0,11	0,8619	-0,48
V_{CC}	504,97 kV	0,00	504,99 Kv	+0,01	505,00 kV	+0,01
I_{CC}	1,9939 kA	-0,31	1,9983 kA	-0,09	2,0004 kA	+0,02
a_{CC}	14,02°	-0,56	14,06°	-0,30	14,15°	+0,35

Obs. : (AC) AC Subsystem; CC Average Value.

Table IV.3: Case V Power Components (h=3).

	p=1%	D%	p=5%	D%	p=10%	D%
$S_{(AC)}$	1166,62 MVA	+0,01	1168,02 MVA	+0,12	1172,38 MVA	+0,49
$P_{(AC)}$	1010,37 MW	0,00	1010,37 MW	0,00	1010,37 MW	0,00
$Q_{(AC)}$	533,49 Mvar	+0,01	534,13 Mvar	+0,12	536,12 Mvar	+0,49
$D_{u\,(AC)}$	4,97 MVA	+49,01	4,97 MVA	+49,18	4,99 MVA	+49,74
$D_{s\,(AC)}$	10,10 MVA	-	50,52 MVA	-	101,04 MVA	-
$D_{h\,(AC)}$	235,41 MVA	-0,01	235,69 MVA	+0,11	236,57 MVA	+0,48
$FP_{(AC)}$	0,8661	0,00	0,8650	-0,12	0,8618	-0,49
V_{CC}	504,97 kV	0,00	504,97 kV	0,00	504,97 kV	0,00
I_{CC}	1,9937 kA	-0,31	1,9937 kA	-0,31	1,9937 kA	-0,31
a_{CC}	14,10°	0,00	14,10°	0,00	14,10°	0,00

Obs. : (AC) AC Subsystem; CC Average Value.