Influence of the Network Reconfiguration in the Performance of Harmonic Filters Located in an Electric Power System

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Abstract

Voltage and current harmonics on an electric power system are consequence from the non-linear operating characteristics of system loads and network components. Power electronic devices, arc furnaces and transformer saturation usually produce the harmonic currents. In order to minimise voltage distortion and improve the power quality of the system, harmonic filters are used and they can be designed and tuned in accordance with the pollution sources, the load demand and the network topology.

In this paper it is studied and analysed the influence of the system reconfiguration in the harmonic distortion, using the software package Harmonique applied to a test power system. Different load levels and changes in power factor compensation were analysed. For each of these scenarios it was studied the influence of the network reconfiguration after the occurrence of a contingency.

Finally, some conclusions that provide a valuable contribution to the better understanding of the current and voltage distortion in order to tune harmonic filters in an electric power system are pointed out.

Key words:

Power Quality, Harmonics, Network Reconfiguration, Electric Power System.

1. Introduction

Harmonic distortion in an electric power system is usually produced by the widely application of power electronic devices (e.g., rectifiers, inverters, cycloconverters, voltage controllers, static VAr sources) and arc furnaces in industry as well as the saturation effect of the network transformers [1], [2].

The harmonic currents produce harmonic voltages in the frequency-dependent impedances of the power system, which are superposed to the sinusoidal supply voltage in all network levels. This may produce overheating, a power factor reduction, interference with telecommunications and the abnormal operation of the protective relying systems [3]. In order to overcome these problems and to improve the power quality, modern electric utilities have been successfully applying harmonic filters in the network and they are designed taking into account the pollution sources, the load demand and the system topology [4].

In this paper it is simulated the effect of some network reconfigurations in the voltage harmonic distortion in a test power system. It was modelled two different industrial harmonic sources, one arc furnace [5] and an ac/dc converter [6], [7]. Changes in network topology may modify voltage distortion and consequently the harmonic filters should be tuned in accordance with these new scenarios. This study was carried out assuming different load demands as well as the required power factor compensation. These simulation results were obtained using the commercial software package HARMONIQUE.

2. Applied Software

The simulation was carried out using the commercial frequency domain simulation software package HARMONIQUE, developed by Electricité de France (EDF). The main feature of these efficient computer programs is to propose a unique solution to various issues with a high degree of performance.

It uses detail models that result from the work of CIGRE committee 36.05 that take into account all the harmonic sources as well as the current and voltage distortion in the power network [8].

3. Application Example

In Figure 1 it is shown the single line diagram of the studied Electric Power System that is fed from the grid system through busbars 1 and 2 (8 transformers, 8 transmission lines and 11 busbars). The simulation was carried out considering the network data presented in Tables I, II and III.

The rated power and the tan (?) of the arc furnace are 6.00 MVA and 0.30 respectively. The data of the ac/dc converter is presented in Table IV.

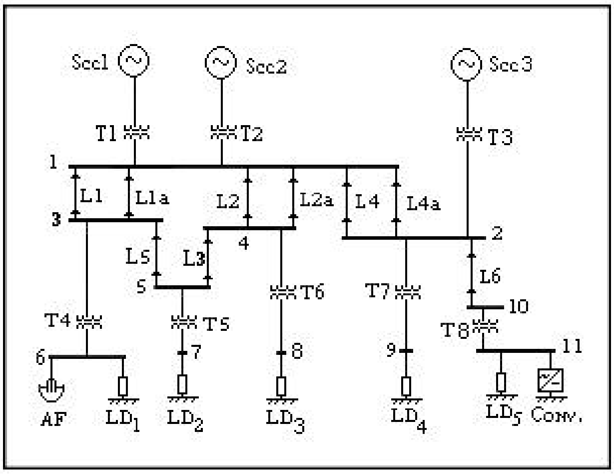

Fig. 1 - Test power network single line diagram.

TABLE I - Transformers data.

Trans-former	Sn [MVA]	Vcc [%]	Vp [kV]	Vs [kV]
T1	36.00	17.0	15.00	150.00
T2	36.00	17.0	15.00	150.00
T3	40.00	15.0	15.00	150.00
T4	25.00	15.0	150.00	60.00
T5	32.00	16.0	150.00	15.00
T6	15.00	11.0	150.00	15.00
T7	15.00	11.0	150.00	15.00
T8	32.00	17.0	150.00	30.00

TABLE II - Lines data.

Lines	R [m? /km]	L [mH/km]	$Q_c/2$ [kVAr/km]	Length [km]
L1	151.00	1,11	0,75	175.60
L1.a	151.00	1,11	0,75	175.60
L2	151.00	1,11	0,75	152,90
L2.a	151.00	1,11	0,75	152,90
L3	171.00	1,91	0,77	24.30
L4	182.00	1,96	0,78	132.20
L4.a	182.00	1,96	0,78	129.80
L5	171.00	1,91	0,77	100.00
L6	143.00	0,94	0,73	200.00

TABLE III - Loads data.

Linear load	P [MW]	Tg (?)
LD_1	5.00	0,70
LD_2	5.00	0.40
LD_3	7.35	0.67
LD_4	4.30	0.60
LD_5	6.60	0.80

TABLE IV - ac/dc Converter data.

Sn [MVA]	type	Ripple voltage rate [%]	Firing angle [?]
5.00	6 pulse	0.00	0.20

The study was carried out considering seven different contingencies (Table V).

TABLE V – Contingencies simulated.

A	$S_{cc}1$ out of service
B	$S_{cc}3$ out of service
C	L_{1a} out of service
D	L_{2a} out of service
E	L_{4a} out of service
F	L_5 out of service
G	L_3 out of service

In the first simulation, it was considered the load levels presented in Table III. In the second simulation, it was analysed the influence of changes in the load demand at busbars 7, 8 and 9. Is only presented the worst case [9] (minimum load level in busbars 7, 8 and 9).

It was also simulated the effect of the capacitor bank compensation in the power network harmonic distortion. These capacitor banks supply a reactive power of 2.00 kVAr, 4.92 kVAr and 2.58 kVAr at busbars 7, 8 and 9 respectively.

In all studied situations the input spectrum currents of the arc furnace and of the ac/dc converter were obtained in accordance with the established models and the corresponding harmonic spectrum are shown in figures 2 and 3. For the arc furnace the most relevant current spectrum component is the 3^{rd} harmonic and it has an amplitude of 4.5% of the fundamental frequency. For the ac/dc converter the most significant current spectrum component is the 5^{th} harmonic and it has an amplitude of 18.5% of the fundamental frequency.

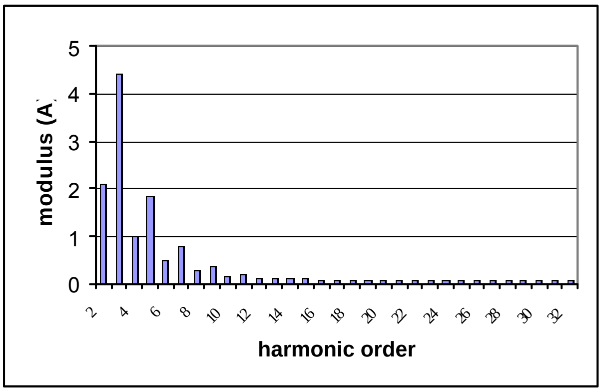

Fig. 2 - Arc furnace injected current.

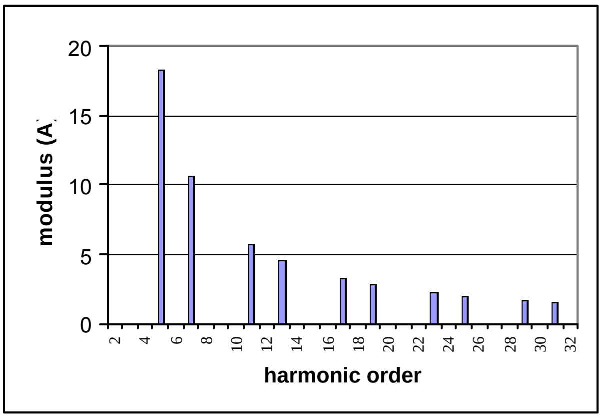

Fig. 3 - ac/dc Converter injected current.

4. Results

All the results show the values obtained for each one of the studied contingencies as well as the solutions associated with the network (BC). All the results are referred to busbars 7 (B_7), 8 (B_8) and 9 (B_9).

In the first scenario it was considered the load demand presented in table III. The THD values obtained are presented in fig. 4.

In the second scenario were considered different load demands in busbars 7, 8 and 9. In fig. 5 are shown the results for the minimum load levels in busbars 7, 8 and 9, that correspond to the worst case.

In the fig. 6 are presented the THD values considering the influence of the capacitor banks compensation in busbars 7, 8 and 9.

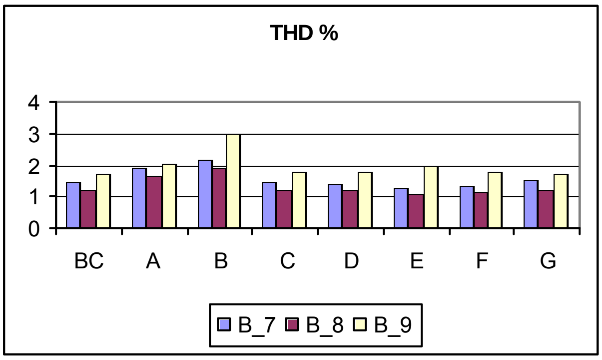

Fig. 4 – THD results for the busbars 7, 8 and 9 considering the different contingencies and the network basic configuration.

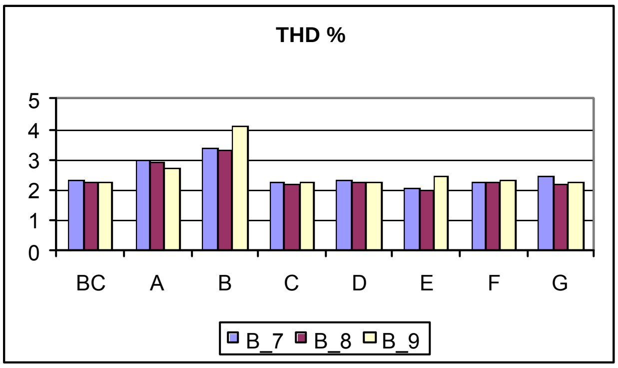

Fig. 5 – THD results for the busbars 7, 8 and 9 considering the minimum load levels in busbars 7, 8 and 9.

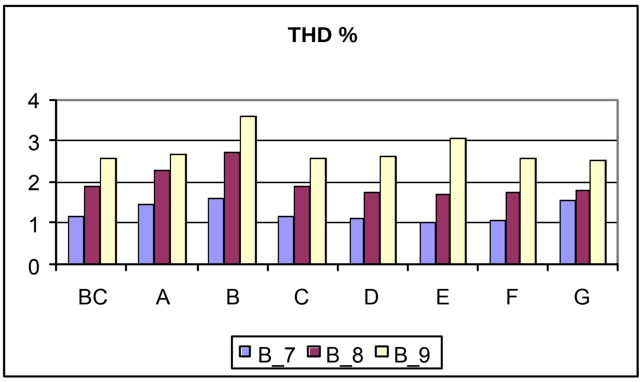

Fig. 6 - THD results for the busbars 7, 8 and 9 considering the influence of the capacitor banks compensation in busbars 7, 8 and 9.

The fig. 7, 8 and 9 show the harmonic voltage amplitude (%) spectrum, in the busbars 7, 8 and 9, respectively, considering the load demand presented in table III.

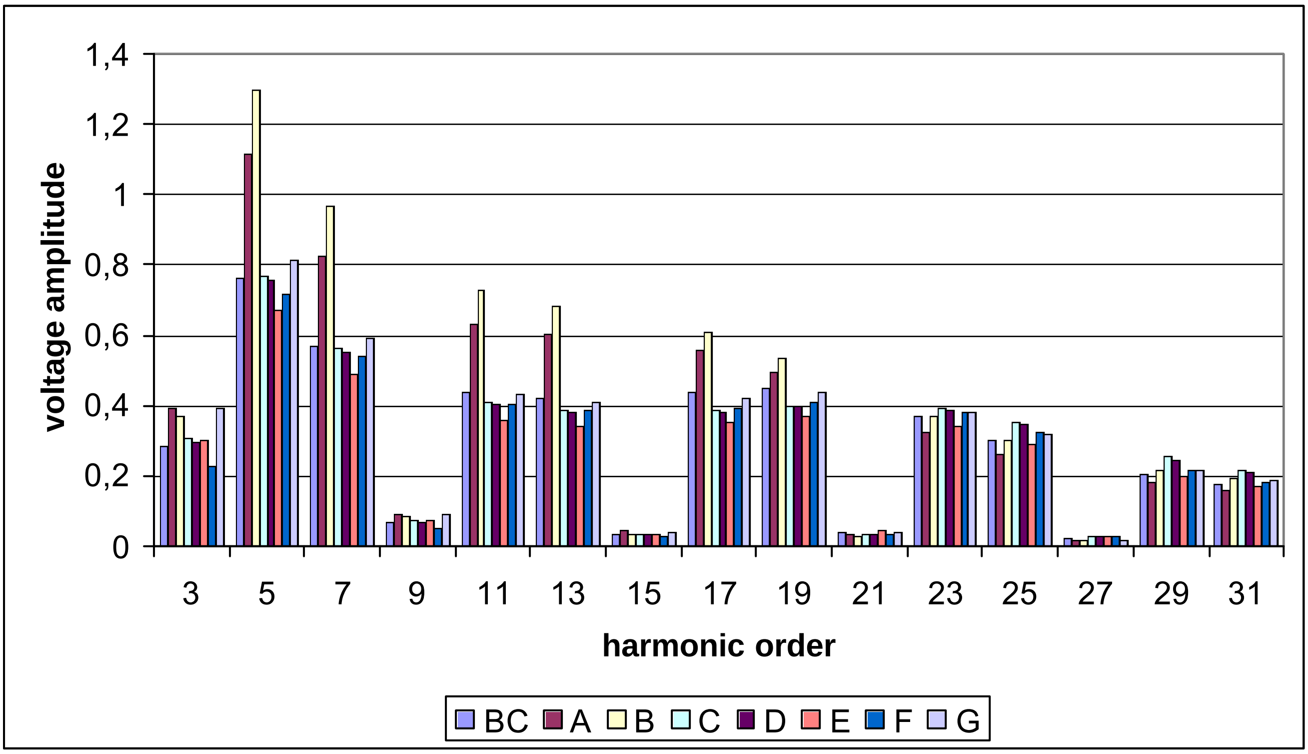

Fig. 7 – Harmonic voltage amplitudes (%) in busbar 7 considering the different contingencies and the network basic configuration, with load demand shown in table III.

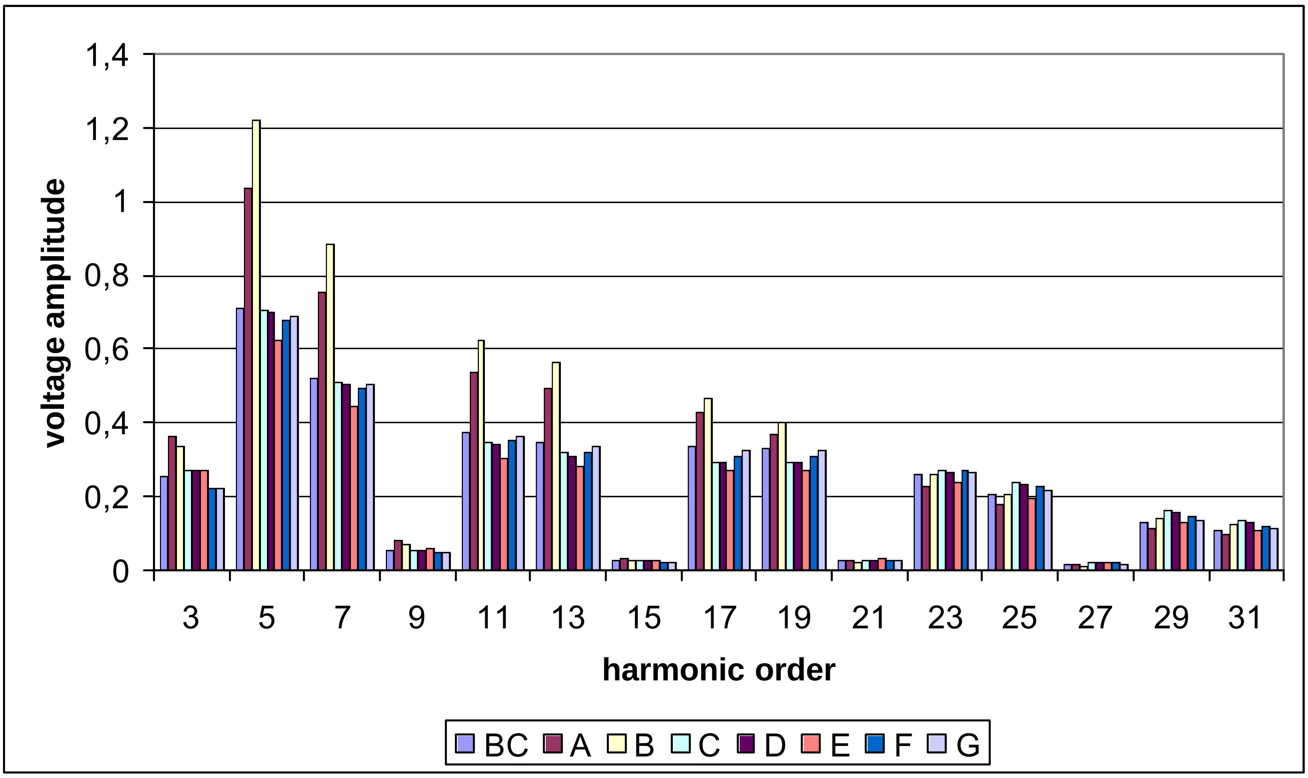

Fig. 8 – Harmonic voltage amplitudes (%) in busbar 8 considering the different contingencies and the network basic configuration, with load demand shown in table III.

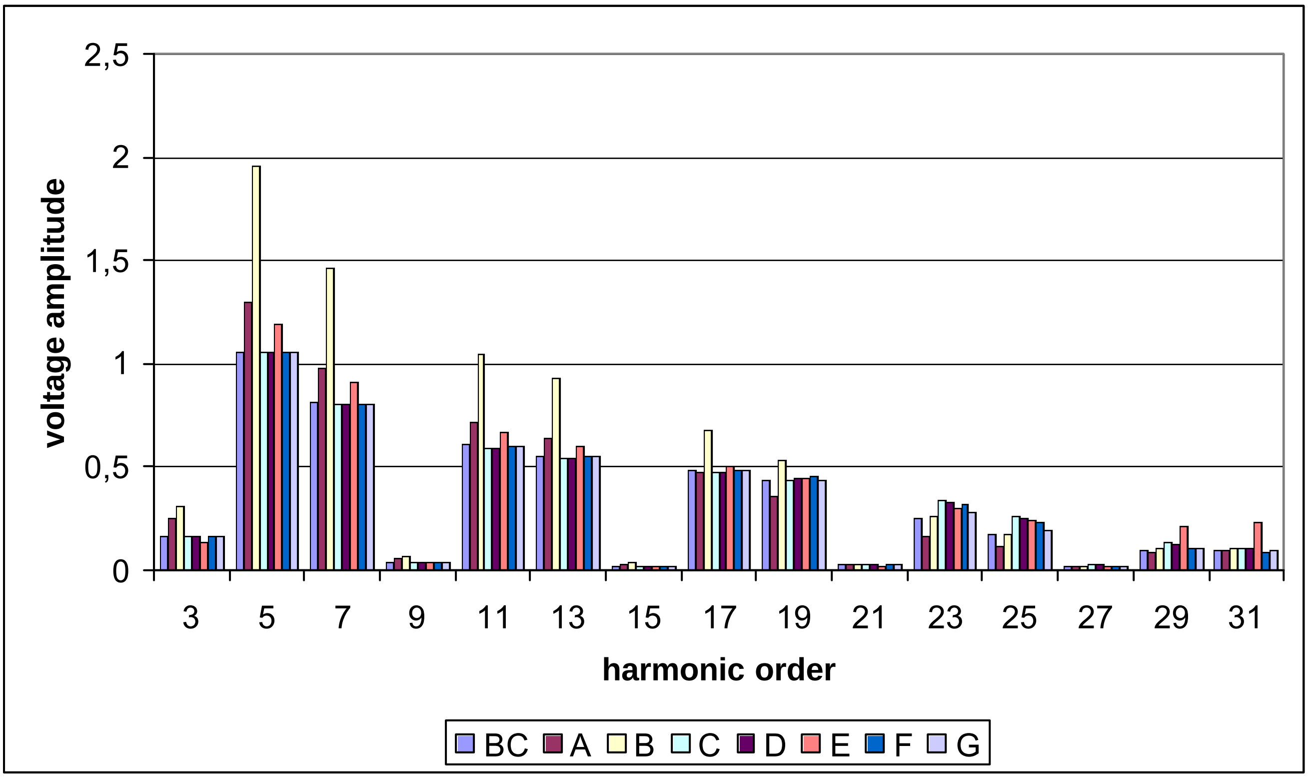

Fig. 9 – Harmonic voltage amplitudes (%) in busbar 9 considering the different contingencies and the network basic configuration, with load demand shown in table III.

5. Conclusions

It was studied and analysed the influence of the network reconfiguration considering different load levels and the power factor compensation in the system harmonic pollution, using the commercial software package HARMONIQUE applied to a test power system.

Observing the fig. 4, the busbar that presents the most severe harmonic pollution is the busbar 9 for all simulations. The most relevant contingency is the B ($S_{cc}3$ out of service), since it presents the biggest THD value (3 % in the busbar 9).

In the situation of minimum load level (0,5 MW) in the busbars 7, 8 and 9, the busbar with bigger harmonic pollution is the 9 for the topology B ($S_{cc}3$ out of service) and E (L_{4a} out of service). In the other topologies the worst case is the busbar 7. The maximum THD value occurs in the busbar 9 with a value grater than 4 %.

Considering the influence of power factor compensation, the most relevant pollution occurs in the busbar 9. For the basic network topology, the THD of the busbar 9 is twice the THD in busbar 7. The value of 3,5 % occurs in the busbar 9 when the $S_{cc}3$ is switched-off .

The fig. 7, 8 and 9 show that however in all the busbars, the B topology take to the grater amplitude for the harmonics 5, 7, 11, 13, 17 and 19, in the other harmonic orders the most relevant contingency isn't the B. For the busbar 9, the biggest values for the 29^{rt} and 31^{rt} harmonics occur for the E contingency.

In the busbar 7 and 8, the A topology ($S_{cc}2$ out of service) produce a strong amplification of the harmonics 3, 5, 7, 11, 13 and 17.

For all simulations it was obtained a similar voltage spectrum although they presented different amplitudes.

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