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# Influences of Pollutant Sources on Harmonic Propagation in a Power Grid

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*Abstract*— **The objective of the present work is to see the influences of number of harmonic sources such as a station of interconnection to high voltage continuous (HVDC), a statics compensator including the thyristor controlled coils (SVC) on the rate of the voltage harmonic distortion in a standard IEEE 14 nodes network and using an iterative approach, then we include filters to reduce harmonic in the pollution caused by these sources network.**

***Keywords*— Voltage harmonic distortion, high voltage direct current (HVDC), static var compensator (SVC), power quality, filters**

## I. INTRODUCTION

Power users at any time anywhere on the network in the best conditions of power, voltage, frequency and safety is the main objective of utilities. Any time, power grids are sensitive to external constraints (lightning ...) as internal constraints (loads they supply) [1]. The proliferation of non-linear and other sensitive equipment in the distribution system and office expenses has increased the need for designing the electrical systems in our buildings by considering issues related to the quality of the wave; These disturbances are of course negative impact on electrical equipment and are now a concern because they are generating a lot of pain and stress, can go a strong heating or sudden stop rotating machines up the total destruction of such equipment. Therefore, energy distributors with the constraint to provide a constant sinusoidal voltage, support the mitigation of harmonic disturbances and voltage dips using high power installations [2]. However, new international regulations impose limits on consumers harmonics generated by their systems, both running in tension. Thus, the filtering of harmonic components is a central concern of distributors on the one hand and users of electric power on the other hand [3], [4].

## II. VALUE CHARACTERIZING A DISTORTED SIGNAL

### A. Total harmonic distortion rate

It provides a measure of the thermal influence of the harmonic , it is the ratio of the RMS value of the fundamental harmonic [ 6 ].

$$THD(\%) = 100.\frac{\sqrt{\sum_{n=2}^{\infty}(G_n)^2}}{G_1} \quad (1)$$

The total harmonic current distortion is given by:

$$THD_i(\%) = 100.\frac{\sqrt{\sum_{n=2}^{\infty}(I_n)^2}}{I_1} \quad (2)$$

$I_n$ : Harmonic Current rank n;
$I_1$ : Fundamental current.
The total harmonic distortion voltage is given by:

$$THD_v(\%) = 100.\frac{\sqrt{\sum_{n=2}^{\infty}(V_n)^2}}{V_1} \quad (3)$$

$V_n$ : harmonic voltage of order n;
$V_1$: fundamental voltage.
The THDi depends only on the effective values of the charging current. However, the function is THDv harmonic currents, the load characteristic, and the short-circuit impedance imposed by the network $Z_{cc}$.

$$THD_v = \frac{\sqrt{\sum_{n=2}^{\infty}(V_n)^2}}{V_1} = \frac{\sqrt{\sum_{n=2}^{\infty}(|Z_{cc}|.I_n)^2}}{V_1} \quad (4)$$

## III. A CHARACTERISTIC OF A SIGNAL

### A. Fourier Analysis

Mathematically, we can decompose any periodic signal into a series of sinusoids whose frequency is a multiple of the fundamental frequency of the signal. This series is called a Fourier series, after the French mathematician Joseph Fourier in the early nineteenth century. If a signal is decomposed to Fourier series, the series is written as follows :

$$G(t) = A_0 + \sum_{n=1}^{\infty} A_n \cos.(n\omega t) + \sum_{n=1}^{\infty} B_n \sin.(n\omega t) \quad (5)$$

With :

$A_0$: DC component or average value of the signal, typically zero electrical distribution steady;

$A_n$ and $B_n$ : Peak amplitudes of the harmonic components of rank n;
$\omega$ : Fundamental pulse.
In electrical usually effective values are used, rather than the peak values. Therefore, the above equation becomes :

$$G(t) = A_0 + \sum_{n=1}^{\infty} \frac{A_n}{\sqrt{2}} . \cos(n\omega t) + \sum_{n=1}^{\infty} \frac{B_n}{\sqrt{2}} . \cos(n\omega t) \quad (6)$$

Coefficients are obtained by analytical or numerical solution of the following integrals :

$$A_0 = \frac{1}{T} \int_0^T G(t).dt \quad (7)$$

$$A_n = \frac{2}{T\sqrt{2}} \int_0^T G(t). \cos(n\omega t).dt \quad (8)$$

$$B_n = \frac{2}{T\sqrt{2}} \int_0^T G(t). \sin(n\omega t).dt \quad (9)$$

Where T is the period of the signal is equal to $\frac{2\pi}{\omega}$ or $\frac{1}{f}$.
The figure 1 shows an example of this decomposition :

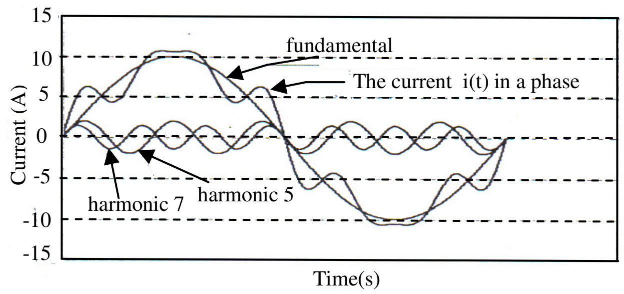


Fig. 1. Distorted wave and its decomposition.

## IV. Mitigation Methods and Procedures

To overcome the problem of harmonic pollution in power grids and industrial facilities, active filtering solutions and liabilities have been developed [7 ], [ 8].

### A. *Active filters*

The purpose of these filters is to generate either currents or harmonic voltages so that the current and voltage are made sinusoidal . The active filter is connected in series or parallel along it is designed respectively to compensate for voltage or current harmonics [6], [9], [10].

### B. *Passive filters*

The principle of a passive filter is to change the impedance of the network , in order to reduce harmonic currents and eliminate harmonic voltages . To do this, the capacitive and inductive elements are combined so as to obtain a connected series resonance at a selected frequency . In our case , we use passive filters . Harmonics 5 , 7, 11 are removed by resonant filters , while 13,17 and 19 harmonics are attenuated by passive damped filters [8].

### C. *Resonant and Damped filter*

The resonant filter is designed to have a very low impedance to the passage of harmonic current determined rank for , it consists of a set of capacitors C and inductance L. detuned Fig. 2 shows the equivalent phase diagram for the installation of a resonant circuit [ 10 ] filter.

A damped filter comprises a capacitor C in series with an assembly consisting of the parallel connection of an inductance L' and a resistor r called damping resistor. It is often used to filter the higher frequencies of the spectrum and not a particular frequency simultaneously. The phase diagram of the installation of a damped filter is shown in Fig. 3.

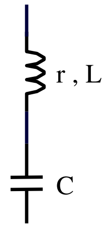


Fig. 2 Resonant filter.

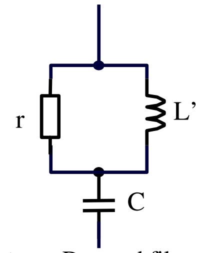


Fig. 3. Damped filter.

## V. Modeling of Pollutant Sources

### A. *Modeling of HVDC (High Voltage Direct Philander)*

The continuous high voltage station (HVDC) is often achieved by operating two power converters in six-phase Graetz bridge through a transformer with two secondary windings with couplings YY and YD (Fig. 4). Harmonic current characteristics of the station are of rank k = 12q ± 1, where q is a positive integer [8].

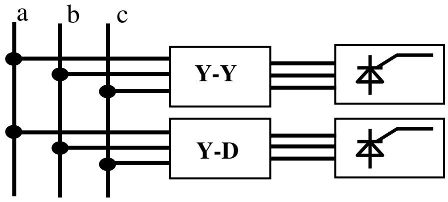


Fig. 4. Diagram of HVDC.

In this example the transformer supplying the HVDC station with a capacity of 135 MVA and voltage level 230 / 35.42kV, its reactance have a 100MVA base is 15%. The filter used at the network node 3 is an assembly of two damped filters whose parameters are : C = 1.25µF, L = 39mH and R = 300Ω (Fig. 5).

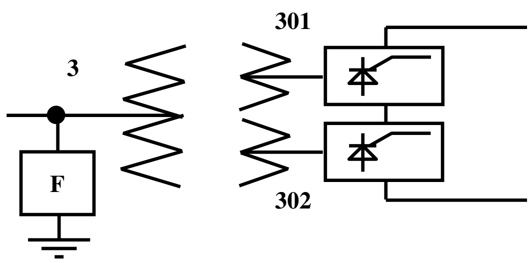


Fig. 5. Representation of HVDC with the filter.

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## VI. Modeling SVC (Static Var Compensator)

Static compensators controlled by thyristors, are considered an efficient and robust means of voltage regulation [8].
They consist, of an inductance L in series with two thyristors connected head to tail and harmonic filters (Fig. 6 and Fig. 7).

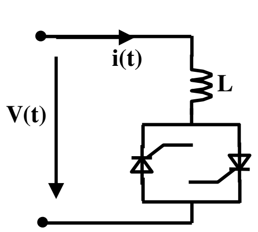


Fig. 6. Diagram of SVC.

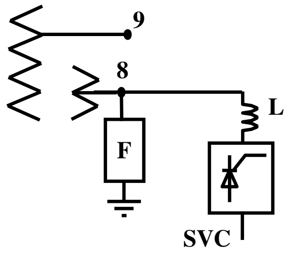


Fig. 7. Representation of the SVC with the filter.

In this paper our static compensator, is powered by a three-winding transformer 230kV, 115kV and 13.8kV, and has an inductance L = 48mH, with a firing angle α = 120 °. i (t) and v (t) are respectively the harmonic current and the voltage applied to the SVC and data as follows: [8].

$$v(t) = \sum_{k=1}^{h} V^{(k)}.\cos(k.\omega.t.\varphi_k) \quad (10)$$

$$i(t) = \begin{cases} \sum_{k=1}^{h} V^{(k)}.(k.\omega.L)^{-1}.[\sin(k.*.T) - \sin(k.*.t_\alpha + \varphi_k)]\ for\ (t_\alpha \le t \le t_e) \\ 0\ for\ 0 < T < t_\alpha\ and\ t_e < t < \frac{T}{2} \end{cases} \quad (11)$$

Where :
$\omega$ :Heartbeat;
$t_\alpha$ :Nothing boot;
$t_e$ : The moment of extinction;
$T$ : Period of the fundamental frequency ;
$L$ : Induction of SVC.

We having a recursive method in MATLAB to calculate the harmonic voltages in the following steps:
1. Determination of the admittance matrix $[Y_{bus}]$ for each harmonic order;
2. Specify parameters for the converter;
3. Determination of the expression of the current drawn by the converter;
4. Calculation of harmonic current spectrum;
5. Calculation of harmonic voltages by solving the system $[V^{(k)}] = [Y_{bus}^{k}] * [I^{(k)}]$.

$[V^{(k)}]$ and $[I^{(k)}]$ are the vectors of voltages and harmonic currents injected at different node.

## VII. Application

The example given is the network standard IEEE 14 [11] which is represented by the diagram (Fig. 8). Two sources are connected to the harmonic network, a station for high voltage DC (HVDC) (Fig. 4) to the node 3 and a static var compensator comprising thyristor controlled by the coils (SVC) (Fig. 6) at the network node 8.

Assume that the linear loads are balanced and that the transmission lines are transposed, the harmonic analysis of direct component is sufficient for determining the levels of harmonic distortion in the network.

Fundamental voltages are obtained by a flow calculation basic power used in [12], [8].

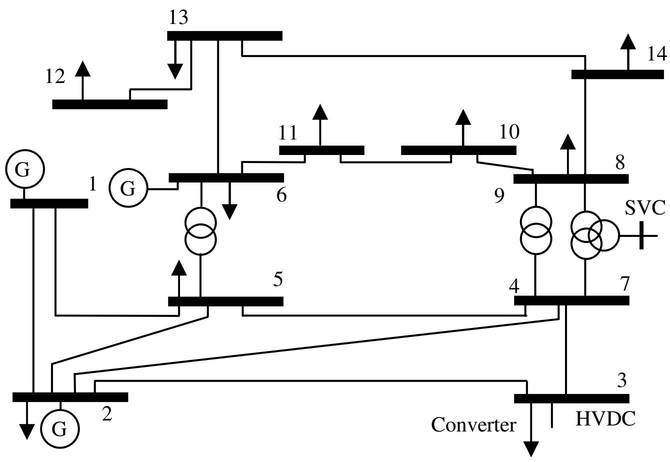


Fig. 8. Network diagram to 14 nodes.

Resonant filters tuned to the harmonic orders 5, 7 and 11 whose parameters are shown in Table 1. provide reactive power 10MVAR and generators are modeled by women in series with subtransient reactance 0.25 pu.

TABLE I
FILTERS USED IN THE COMPENSATOR

| Harmonic order | R(Ω) | L(mH) | C(µF) |
|---|---|---|---|
| 5 | 1 | 6.7 | 42 |
| 7 | 1 | 3.4 | 42 |
| 11 | 1 | 1.39 | 42 |

The data are shown in the network (Tables 2and 3).

TABLE II
POWER GENERATORS NODES

| Nodes | Voltage | P(kW) | Q(kVAr) |
|---|---|---|---|
| 1Slack | 1.0600 | 261.681 | -28.633 |
| 2PV | 1.0450 | 18.200 | 5.857 |
| 6PV | 1.0700 | -11.200 | 44.2 |

TABLE III
POWERS INVOLVED

| Nodes | Rated voltage (kV) | Loads (kW) | Loads (kVAr) |
|---|---|---|---|
| 1 | 230 | 0 | 0 |
| 2 | 230 | 0 | 0 |
| 3 | 230 | 0 | 0 |

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| | | | |
|---|---|---|---|
| 4 | 230 | 47790 | -3900 |
| 5 | 230 | 7599 | 1599 |
| 6 | 230 | 0 | 0 |
| 7 | 13.8 | 0 | 0 |
| 8 | 115 | 0 | 0 |
| 9 | 115 | 29499 | 12900 |
| 10 | 115 | 9000 | 5799 |
| 11 | 115 | 3501 | 11800 |
| 12 | 115 | 6099 | 16599 |
| 13 | 115 | 13500 | 5799 |
| 14 | 115 | 14901 | 5051 |
| 301 | 35.4 | 59505 | 3363 |
| 302 | 35.4 | 59505 | 3363 |

## VIII. Results and Interpretation

The results of figures below illustrate the variation of total harmonic distortion voltage THDv in different network nodes and the influence of the filters on the harmonic distortion of pollutant sources, and for the following three configurations :

- SVC alone;
- HVDC alone;
- SVC and HVDC together.

### A. *Firing angle of the HVDC for α=30°*

First, we will visualize the curves THDv nodes according to the study of three cases, with a firing angle α of the HVDC equal to 30 °.

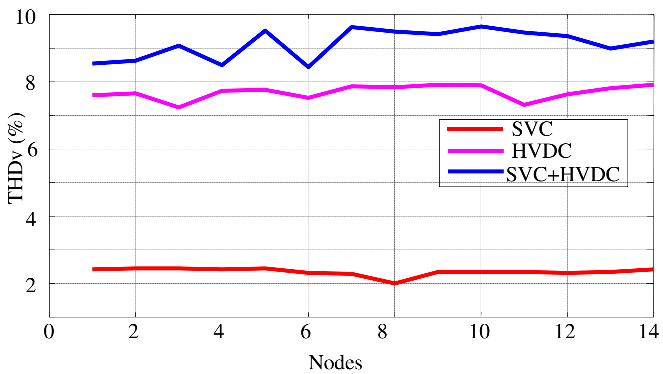


Fig. 9. Variation of THDv as a function sources of pollution, without filtering

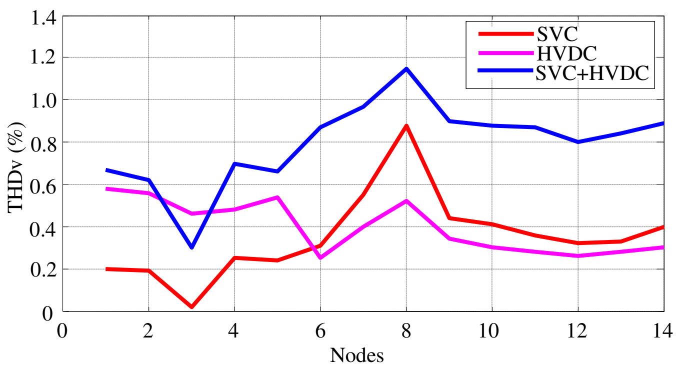


Fig. 10. Variation of THDv as a function sources of pollution, with filtering

### B. *Firing angle of the HVDC for α=45°*

Secondly, we use the same steps to see the variation of THDv in different nodes of the network, but with a firing angle α of the HVDC equal to 45°

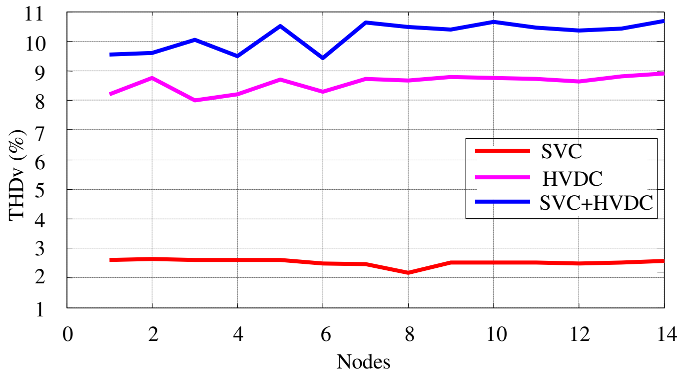


Fig. 11. Variation of THDv as a function sources of pollution, without filtering

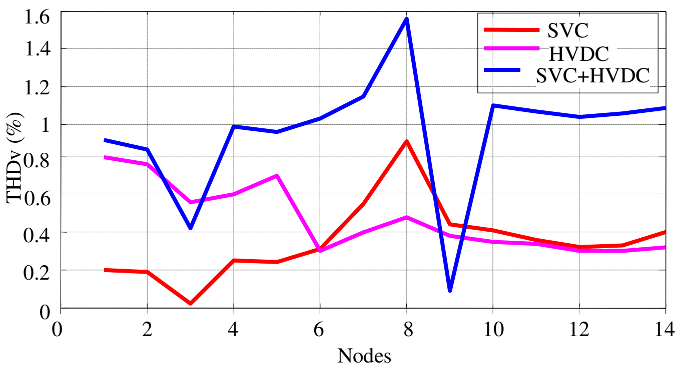


Fig. 12. Variation of THDv as a function sources of pollution, with filtering

The previous example explains the influence of different harmonic sources on the rate of harmonic voltage distortion and the effect of filters on them.

In curves Fig. 9 and Fig. 11 where the assembly is without a filter, it is clear that the SVC has no significant effect on the harmonic voltage distortion , since the largest value of THDv is only 2.44 %, while HVDC contributes significantly to the harmonic pollution especially when the firing angle is large , for example for α = 45° was THDv was 8.90% and that in which α = 30° is 7.91 % more, there is a weak interaction between the SVC and HVDC ( THDv = 10.68% for α = 45° and THDv = 9.683 % for α = 30° ) when placing together the two sources relative to one HVDC.

Against by the figures Fig. 10 and Fig. 12 shows that the filters placed at the nodes are connected where pollution sources ( node 3 for HVDC and SVC node 8) as well as the coupling YY and YD transformer supplying the HVDC influence on the variation of THDv for different network nodes. Indeed, we find that the total harmonic distortion voltage decreases to 0.88 % respectively for the SVC, 0.80 % and 0.58 % respectively for the HVDC for α = 45 °, α = 30 ° and 1.56 %, 0.97 % for the SVC and HVDC ( α = 45 °, α = 30 °, respectively ) together.

## IX. CONCLUSIONS

In this paper, we developed an iterative method for calculating the variation of harmonic distortion in voltage in an electrical network THDv standard IEEE 14 containing a particular HVDC (High Voltage Direct Current) station and SVC (Var Compensator Statistic ).

The results showed low contribution to the harmonic pollution of SVC compared to those of single HVDC, HVDC and SVC as well as a small contribution compared to the firing angle of the HVDC power converter. Hence it provides an increase in performance by varying the angle of a value to another, and the great influence of resonant filters and passive filters amortized over the level of harmonic voltage distortion THDv.

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