International Journal of Electrical and Computer Engineering (IJECE)
Vol. 2, No.5, October 2012, pp. 681~690
ISSN: 2088-8708

Design of a Computer Code To Evaluate the Influence of the Harmonics in the Electrical Networks

A. Souli*, A. Hellal**
*Nuclear Research Center of Birine-Algeria,
** LACoSERE Laboratory, Electrical engineering Department, Laghouat University- Algeria,

Article Info

Article history:

Received Aug 11, 2012
Revised Oct 2, 2012
Accepted Oct 11, 2012

Keyword:

Power Flow
Harmonics in Electrical Networks
HPFCODE
MATLAB

ABSTRACT

This paper aims to present the design of a computer code (HPFCODE), for calculate a power flow and power losses in power systems under the influence of harmonics, using the GUI in MATLAB. After described the program was run for two networks IEEE 6 nodes and IEEE 14 nodes. The power flow by Newton-Raphson method was calculated as the losses of active and reactive power in the lines, respectively, where the loads are linear and nonlinear (Static Var Compensator(SVC), Thyristor controlled Reactor(TCR), and Unified Power Flow Controller ((UPFC)), The results were almost consistent and show the influence of higher harmonics on power losses in electrical networks

Corresponding Author:

A. Souli
Researcher in Nuclear Research Center of Birine,
Laghouat University- Algeria,
e-mail:souliaissa@yahoo.fr

1. INTRODUCTION

Power system harmonic analysis is to determine the impact of harmonic producing loads on a power system [1]. Harmonic analysis has been widely used for system planning, operation criteria development, equipment design, troubleshooting, verification of standard compliance, and so on. Over the past two decades, significant efforts and progresses have been made in the area of power system harmonic analysis. Well-accepted component models, simulation methods and analysis procedures for conducting harmonic studies have been established. Harmonic studies are becoming an important component of power system analysis and design.

The HPFCODE "Code Harmonics Power Flow" is a program of simulation and calculation of power flow [2], power grids, can give the results of power flow in the nodes, power flow and power losses in the lines, in the network system to select IEEE 6 nodes, or IEEE 14 nodes. The HPFCODE calculates of the harmonics power flow [3] in the nodes, lines, power losses in the lines, and also in the normal case (no harmonics). Through the HPFCODE code, we can calculate the power flow of a power system with linear loads or with a nonlinear load any (SVC TCR, UPFC……), by the choice of a preferred network and the nonlinear load which we prefer, and running the program.

2. STRUCTURE OF HPFCODE

Our program is called HPFCODE was developed to calculate the power flow and power losses [4] in the lines for various systems of the power grids. HPFCODE can analyzed and calculate the power flow (power flow) in two cases: PFNormal where the loads are linear and PFHarmonic where there are non-linear loads (SVC, TCR, and UPFC) [5].

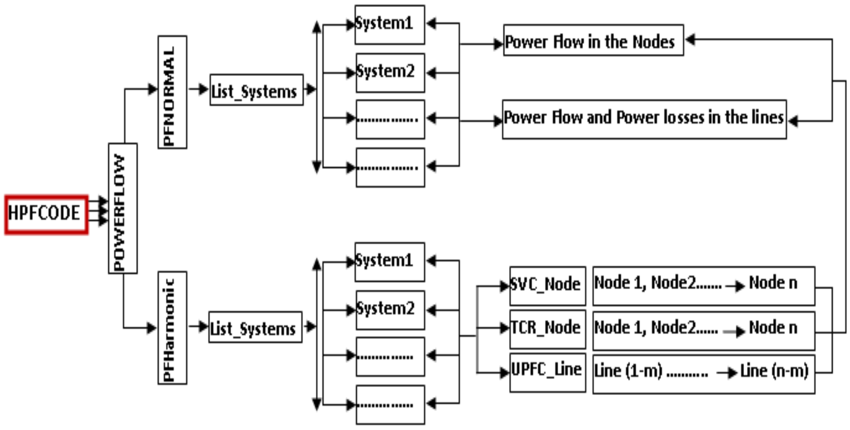

Figure 1. Structure of program HPFCODE

HPFCODE is a computer code produced in MATLAB [6], and allows you to run multiple applications and functions (MATLAB files). HPFCODE structure is based on graphical interfaces [7] performed by MATLAB (GUI).

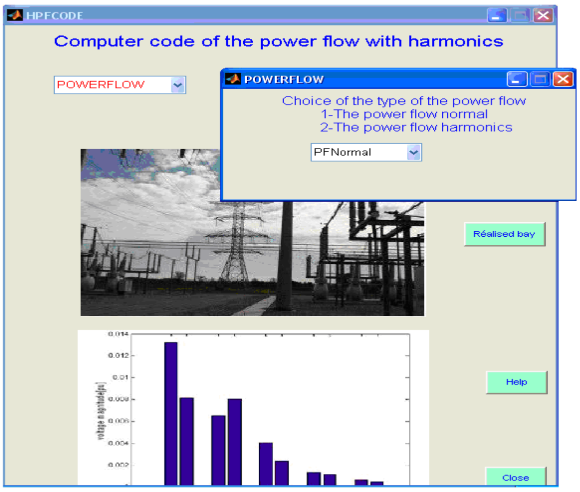

Figure 2. Principal Window of HPFCODE program

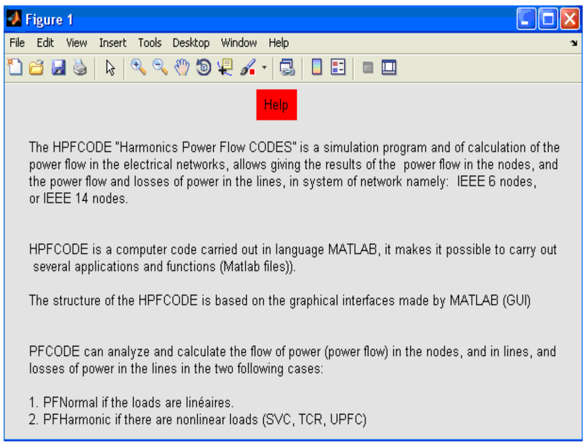

Figure 3. Help Window of HPFCODE program

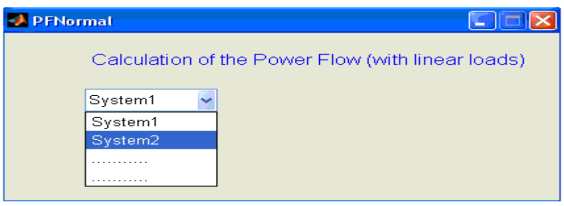

Figure 4. Network System selection with PFNormal

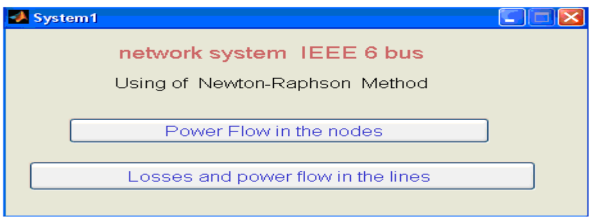

Figure 5. Results of the network system 1

First, the GUI displays a HPFCODE home page that mentions the objective of this program code for calculating the harmonic power flow with " a subroutine is called POWERFLOW, and three buttons:

- The first button is "Directed by" the author of this program HPFCODE.
- The second button is "Help" gives an overview of the program.
- The third button "Close" to exit the HPFCODE program.

If you click on the first function PFNormal the following window. If you click on System1, System2, etc.., another window appears, and you can select one of two functions: Perform a power calculation in normal nodes (without the presence of harmonics) or calculate the normal power and power losses in the lines of the network system that was chosen. By cons, if you press on the first function PFHarmonic the following window is:

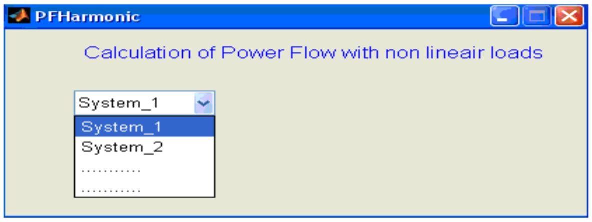

Figure 6. Network System selection with PFHarmonic

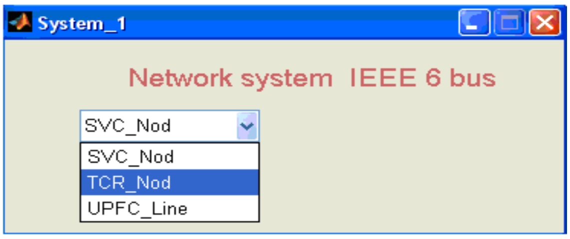

Figure 7. Network System 1 with non Linear Loads

Then click on System1 [8], System2 [9], or System (the study system available in the database), gives a window of a choice for non-linear loads on power system chosen

If you selected the first non-linear load SVC represented by "SVC_Nod" window of Figure 8 appears with a choice of location of SVC node to select. If you click on other nonlinear loads TCR represented by " TCR_Nod " or UPFC represented by " UPFC_Line "a window similar to Figure 8 appears. For "UPFC_Line, the siting of UPFC is compared to the lines of the system studied.

3. DEVICES OF GENERATION OF HARMONICS

The Harmonics are created by devices, the voltage / current is not linear [10], as is the case with power electronic converters and motor drives. Among the harmonic generators, we can mention: Non-linear loads: Static Var Compensator (SVC), Thyristor controlled Reactor (TCR), Unified Power Flow Controller (UPFC):

- Six-phase Rectifier Bridge.
- Switch Mode type computer.
- Lighting load.
- Variable speed.

Among the non-linear loads used in power systems, which generate harmonics, we distinguish mainly FACTS systems "Flexible Alternating Current Transmission System" [11]. These devices are in general use of power electronics, microprocessors, automation, telecommunications and software to achieve control power systems. These are some fast answers. They are, in principle more flexible control of power flow. They also can load the transit lines to values near their thermal limit, and increase the ability to transfer power from one region to another. They also limit the effects of faults and equipments failures, and stabilized the network behavior. But they are a source of harmonics currents often undesirable.

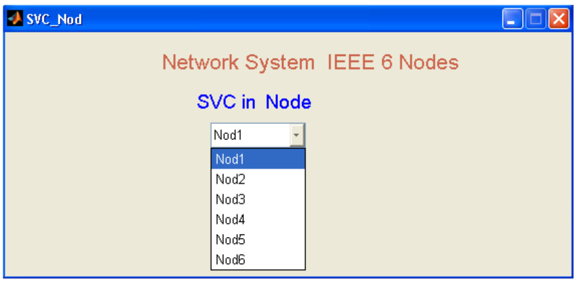

Figure 8. Possible Nodes of Hiring of the SVC in the Study System

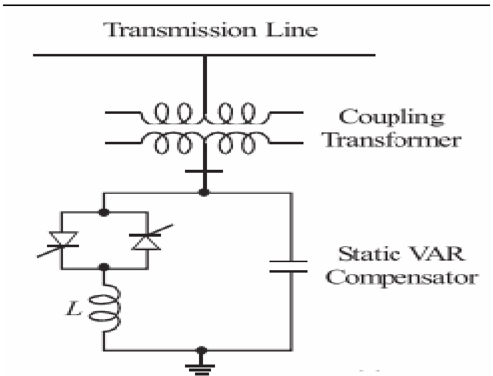

Figure 9. SVC connected to a transmission line

4. STATIC VAR COMPENSATOR (SVC) DESCRIPTION AND MODELING:

The SVC uses conventional thyristors to achieve fast control of shunt-connected capacitors and reactors. The configuration of the SVC is shown in Figure 9, which basically consists of a constant capacitor(C) and a thyris-tor controlled reactor (L).The delay angle control of the thyristor banks determines the equivalent shunt admittance presented to the power system [12].

New version of SVC is basically a shunt connected static var generator/load whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables; typically, the controlled variable is the SVC bus voltage [13].One of the major reasons for installing a SVC is to improve Dynamic voltage control and thus increase system load ability. An additional stabilizing signal, and supplementary control, super imposed on the voltage control loop of a SVC can provide damping of system oscillation as discussed .In this paper, the SVC is basically represented by a variable reactance with maximum inductive and capacitive limits to control the SVC bus voltage, with an additional control block and signals to damp oscillations, as shown in Figure 10.

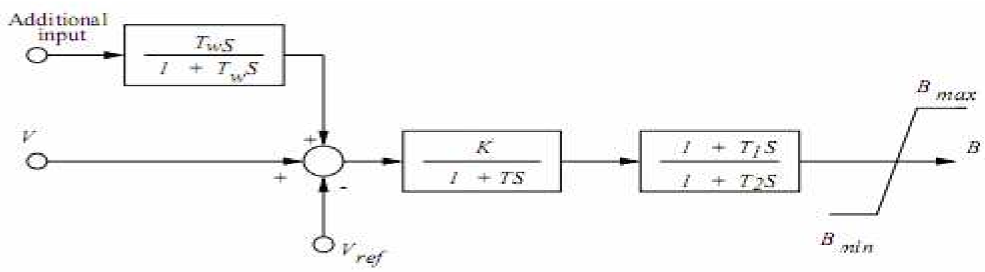

Figure 10: Structure of SVC controller with oscillation damping, where B is the equivalent shunts susceptance of the controller

The model considers SVC as shunt-connected variable susceptance, BSVC which is adapted automatically to achieve the voltage control. The equivalent susceptance, Beq is determined by the firing angle "of the thyristors that is defined as the delay angle measured from the peak of the capacitor voltage to the firing instant.The fundamental frequency equivalent neglecting harmonics of the current results [14].

$$B_{eq} = B_L(\alpha) + B_c \quad (1)$$

$$B_L(\alpha) = -\frac{1}{\omega L}\left(1 - \frac{2\alpha}{\pi} - \frac{\sin(2\alpha)}{\pi}\right), B_c = \omega C \text{ and } 0^0 \le \alpha \le 90^0 \quad (2)$$

If the real power consumed by the SVC is assumed to be zero, then:

$$P_{svc} = 0 \quad (3)$$

$$Q_{svc} = -B_{svc} * V^2 \quad (4)$$

That, “V” is the bus voltage magnitude

As the reactive power demand at the bus varies, the susceptance is varied subject to the limits. However, the reactive power is a function of the square of the bus voltage. Hence the reactive power generated decreases as the voltage decreases.

5. CALCULATION OF THE HARMONIC POWER FLOW

A regular program for calculated the load flow was used to calculate the harmonic active and reactive power, currents and amplitudes and phases of nodal voltages. This program implements the Newton – Raphson[15] for calculating the system of equations that represent the balance of active and reactive nodal powers.

The process of compute the flow of harmonic power grid is as follows:
1. First, a load flow is calculated for a fundamental frequency. The nodal voltage magnitudes obtained are used to convert the power load admittances.

$$Y_{ia} - jY_{ir} = \frac{P_i}{V_i^2} - j\frac{Q_i}{V_i^2} \quad (5)$$

2. Then the admittances, load modeling, have been recalculated for the harmonic of order *h*

$$Y_{ia}^h - jY_{ir}^h = \frac{P_i}{V_i^2\sqrt{h}} - j\frac{Q_i}{V_i^2\sqrt{h}} \quad (6)$$

3. The impedance of the transformer for the harmonic of order ***h*** is given like [10]

$$Z_{tf} = R_t\sqrt{h} + jX_t h \quad (7)$$

With $\boldsymbol{R_t}$ and $\boldsymbol{X_t}$ impedances of transformer at the fundamental frequency.

4. For the circuit $\boldsymbol{\pi}$ equivalent of the line of transmission, its specific impedance for the harmonic of order h is calculated by the relation:

$$Z_0 = R_0 + jX_0 h = R_0 + j2\pi L_0 h \quad (8)$$

and the specific admittance by:

$$Y_0 = G_0 + jB_0 h = G_0 j2\pi C_0 h \quad (9)$$

The impedance $\boldsymbol{Z_e}$ and admittance $\boldsymbol{Y_e}$, of the circuit $\boldsymbol{\pi}$ in a long line are determined as

$$Z_e = R_e + jX_e = real\,(Z_e) + j.imag\,(Z_e)$$
$$= Z_c sh(\gamma_0 l) = Z_c\left(\frac{e^{\gamma_0 l} - e^{-\gamma_0 l}}{2}\right) \quad (10)$$

Where $Z_c = \sqrt{\frac{Z_0}{Y_0}}$ is the impedance of the wave $\gamma_0 = \sqrt{Z_0 Y_0}$, is a factor of wave propagation and L the length of the line.

The data corrected on the parameters of the electrical supply elements of the network were transferred to the calculation program from flow from load.

6. SIMULATIONS WITH HPFCODE

6.1. Nomenclature

Symbols	Description
SVC	Static Var Componsator
TCR	Thyristor Controlled Reactor
$UPFC$	Unified Power Flow Control
Y	The Admittance
Y^h	The harmonic Admittance of order *h*
V_i	The voltage magnitudes of the node *i*
P_i	The Active Power of the node *i*
Q_i	The Reactive Power of the node *i*

6.2. The Network Systems of the Test

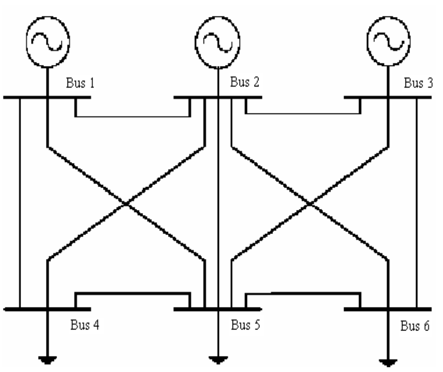

Figure 9. Network System 6 bus, 11Lines

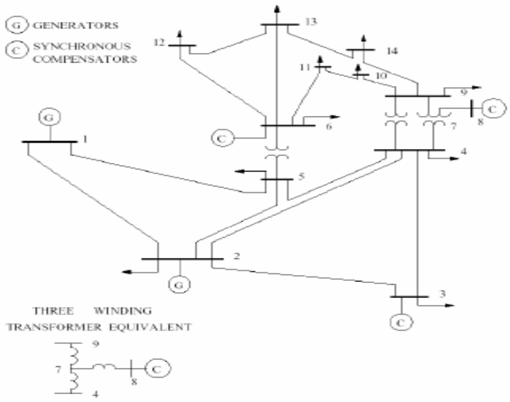

Figure 10. Network System 14 bus, 20 Lines

6.3. Power Flow (PFNormal)

6.3.1. Example1: Network System 6 bus, 11 Lines

Table 1. Power Flow of Nodes

Newton Raphson Loadflow Analysis									
Bus No	V pu	Angle Degree	Injection MW	Injection MVar	Generation MW	Generation Mvar	Load MW	Load MVar
1	1.0500	0.0000	1.427	-48.609	1.427	-48.609	0.000	0.000
2	1.0800	-0.6399	0.500	4.926	0.500	4.926	0.000	0.000
3	1.0800	-0.6270	0.600	-13.289	0.600	-13.289	0.000	0.000
4	1.0758	-0.4899	-0.700	-0.700	-0.000	-0.000	0.700	0.700
5	1.0832	-0.6745	-0.700	-0.700	0.000	0.000	0.700	0.700
6	1.0840	-0.7046	-0.700	-0.700	0.000	0.000	0.700	0.700
Total			0.427	-59.072	2.527	-56.972	2.100	2.100

Table 2. Power flow and power losses in the lines

Line FLow and Losses									
From Bus	To Bus	P MW	Q MVar	From Bus	To Bus	P MW	Q MVar	Line Loss MW	Line Loss MVar
1	2	-1.220	-15.105	2	1	1.428	15.521	0.208	0.417
1	4	1.365	-13.857	4	1	-1.277	14.209	0.088	0.352
1	5	1.282	-11.929	5	1	-1.177	12.321	0.104	0.392
2	3	-0.101	0.020	3	2	0.101	-0.020	0.000	0.000
2	4	-0.611	4.862	4	2	0.621	-4.842	0.010	0.021
2	5	-0.132	-1.101	5	2	0.133	1.105	0.001	0.003
2	6	-0.084	-2.129	6	2	0.087	2.137	0.003	0.008
3	5	-0.195	-1.231	5	3	0.197	1.235	0.002	0.003
3	6	0.694	-4.456	6	3	-0.691	4.474	0.003	0.017
4	5	-0.044	-1.966	5	4	0.051	1.979	0.007	0.013
5	6	0.097	-0.327	6	5	-0.096	0.327	0.000	0.000
Total Loss								0.427	1.226

6.3.2. Example 2: Network System 14 bus, 20 Lines

Table 3. Power Flow of Nodes

Newton Raphson Loadflow Analysis

Bus No	V pu	Angle Degree	Injection MW	Injection MVar	Generation MW	Generation Mvar	Load MW	Load MVar
1	1.0600	0.0000	232.593	-15.233	232.593	-15.233	0.000	0.000
2	1.0450	-4.9891	18.300	35.228	40.000	47.928	21.700	12.700
3	1.0100	-12.7492	-94.200	8.758	0.000	27.758	94.200	19.000
4	1.0132	-10.2420	-47.800	3.900	0.000	0.000	47.800	-3.900
5	1.0166	-8.7601	-7.600	-1.600	-0.000	-0.000	7.600	1.600
6	1.0700	-14.4469	-11.200	15.526	0.000	23.026	11.200	7.500
7	1.0457	-13.2368	0.000	0.000	0.000	0.000	0.000	0.000
8	1.0800	-13.2368	0.000	21.030	0.000	21.030	0.000	0.000
9	1.0305	-14.8201	-29.500	-16.600	-0.000	-0.000	29.500	16.600
10	1.0299	-15.0360	-9.000	-5.800	-0.000	0.000	9.000	5.800
11	1.0461	-14.8581	-3.500	-1.800	0.000	0.000	3.500	1.800
12	1.0533	-15.2973	-6.100	-1.600	0.000	0.000	6.100	1.600
13	1.0466	-15.3313	-13.500	-5.800	0.000	0.000	13.500	5.800
14	1.0193	-16.0717	-14.900	-5.000	-0.000	0.000	14.900	5.000
Total			13.593	31.009	272.593	104.509	259.000	73.500

Table 4. Power flow and power losses in the lines

Line FLow and Losses

From Bus	To Bus	P MW	Q MVar	From Bus	To Bus	P MW	Q MVar	Line Loss MW	Line Loss MVar
1	2	157.080	-17.484	2	1	-152.772	30.639	4.309	13.155
1	5	75.513	7.981	5	1	-72.740	3.464	2.773	11.445
2	3	73.396	5.936	3	2	-71.063	3.894	2.333	9.830
2	4	55.943	2.935	4	2	-54.273	2.132	1.670	5.067
2	5	41.733	4.738	5	2	-40.813	-1.929	0.920	2.809
3	4	-23.137	7.752	4	3	23.528	-6.753	0.391	0.998
4	5	-59.585	11.574	5	4	60.064	-10.063	0.479	1.511
4	7	27.066	-15.396	7	4	-27.066	17.327	0.000	1.932
4	9	15.464	-2.640	9	4	-15.464	3.932	0.000	1.292
5	6	45.889	-20.843	6	5	-45.889	26.617	0.000	5.774
6	11	8.287	8.898	11	6	-8.165	-8.641	0.123	0.257
6	12	8.064	3.176	12	6	-7.984	-3.008	0.081	0.168
6	13	18.337	9.981	13	6	-18.085	-9.485	0.252	0.496
7	8	-0.000	-20.362	8	7	0.000	21.030	0.000	0.668
7	9	27.066	14.798	9	7	-27.066	-13.840	0.000	0.957
9	10	4.393	-0.904	10	9	-4.387	0.920	0.006	0.016
9	14	8.637	0.321	14	9	-8.547	-0.131	0.089	0.190
10	11	-4.613	-6.720	11	10	4.665	6.841	0.051	0.120
12	13	1.884	1.408	13	12	-1.873	-1.398	0.011	0.010
13	14	6.458	5.083	14	13	-6.353	-4.869	0.105	0.215
Total Loss								13.593	56.910

6.4. Harmonic Power Flow (Pfharmonic)
6.4.1. Example1: Network System 6 bus, 11 Lines
6.4.1.1. Our example is the SVC in nodes 5

Table 5. Power Flow of Nodes

Newton Raphson Loadflow Analysis									
Bus No	V pu	Angle Degree	Injection MW	Injection MVar	Generation MW	Generation Mvar	Load MW	Load MVar
1	1.0500	0.0000	1.502	-52.528	1.502	-52.528	0.000	0.000
2	1.0800	-0.6918	0.500	6.978	0.500	6.978	0.000	0.000
3	1.0800	-0.6997	0.600	-11.243	0.600	-11.243	0.000	0.000
4	1.0755	-0.5240	-0.700	-0.700	-0.000	-0.000	0.700	0.700
5	1.0795	-0.6952	-0.700	-0.700	-0.000	-0.000	0.700	0.700
6	1.0835	-0.7648	-0.700	-0.700	0.000	-0.000	0.700	0.700
Total			0.502	-58.894	2.602	-56.794	2.100	2.100

Table 6. Power flow and power losses in the lines

Line FLow and Losses									
From Bus	To Bus	P MW	Q MVar	From Bus	To Bus	P MW	Q MVar	Line Loss MW	Line Loss MVar
1	2	-0.807	-15.305	2	1	1.020	15.732	0.213	0.426
1	4	1.714	-13.799	4	1	-1.627	14.149	0.088	0.351
1	5	0.594	-15.707	5	1	-0.415	16.155	0.179	0.448
2	3	0.062	-0.012	3	2	-0.062	0.012	0.000	0.000
2	4	-0.781	5.243	4	2	0.793	-5.219	0.012	0.024
2	5	0.126	0.183	5	2	-0.126	-0.183	0.000	0.000
2	6	0.073	-1.919	6	2	-0.071	1.926	0.002	0.006
3	5	0.111	0.224	5	3	-0.111	-0.224	0.000	0.000
3	6	0.550	-3.898	6	3	-0.547	3.911	0.003	0.013
4	5	0.134	-1.534	5	4	-0.130	1.540	0.004	0.006
5	6	0.082	-1.090	6	5	-0.081	1.094	0.001	0.004
Total Loss								0.502	1.279

6.4.2. Example 2: Network System 14 bus, 20 Lines
6.4.2.1. Our example is the SVC in nodes 7

Table 7. Power Flow of Nodes

Newton Raphson Loadflow Analysis

Bus No	V pu	Angle Degree	Injection MW	Injection MVar	Generation MW	Generation Mvar	Load MW	Load MVar
1	1.0600	0.0000	232.596	-17.825	232.596	-17.825	0.000	0.000
2	1.0450	-4.9814	18.300	27.702	40.000	40.402	21.700	12.700
3	1.0100	-12.7104	-94.200	4.497	-0.000	23.497	94.200	19.000
4	1.0203	-10.3508	-47.800	3.900	0.000	0.000	47.800	-3.900
5	1.0222	-8.8158	-7.600	-1.600	0.000	0.000	7.600	1.600
6	1.0800	-14.2033	-11.200	-10.702	0.000	-3.202	11.200	7.500
7	1.0670	-13.3825	-0.000	-0.000	-0.000	-0.000	0.000	0.000
8	1.0900	-13.3825	0.000	14.211	0.000	14.211	0.000	0.000
9	1.0664	-14.9423	-29.500	-16.600	0.000	-0.000	29.500	16.600
10	1.0614	-15.0920	-9.000	-5.800	-0.000	-0.000	9.000	5.800
11	1.0671	-14.7772	-3.500	-1.800	0.000	0.000	3.500	1.800
12	1.0750	-15.1924	-6.100	-1.600	0.000	0.000	6.100	1.600
13	1.0785	-15.6254	-13.500	-5.800	-0.000	-0.000	13.500	5.800
14	1.0872	-17.0226	-14.900	-5.000	0.000	0.000	14.900	5.000
Total			13.596	-16.417	272.596	57.083	259.000	73.500

Table 8. Power flow and power losses in the lines

Line FLow and Losses

From Bus	To Bus	P MW	Q MVar	From Bus	To Bus	P MW	Q MVar	Line Loss MW	Line Loss MVar
1	2	156.848	-17.430	2	1	-152.552	30.545	4.296	13.115
1	5	75.748	5.335	5	1	-72.975	6.112	2.773	11.446
2	3	73.116	5.964	3	2	-70.800	3.792	2.316	9.756
2	4	56.181	-1.229	4	2	-54.501	6.327	1.680	5.099
2	5	41.556	1.442	5	2	-40.654	1.311	0.902	2.753
3	4	-23.400	3.591	4	3	23.768	-2.652	68	0.940
4	5	-61.383	15.666	5	4	61.897	-14.043	0.515	1.623
4	7	28.154	-22.565	7	4	-28.154	25.123	-0.000	2.558
4	9	16.161	-8.070	9	4	-16.161	9.760	0.000	1.689
5	6	44.132	-23.061	6	5	-44.132	28.634	0.000	5.573
6	11	7.451	3.450	11	6	-7.396	-3.335	0.055	0.115
6	12	7.214	-1.292	12	6	-7.157	1.409	0.057	0.118
6	13	18.267	-7.726	13	6	-18.044	8.165	0.223	0.439
7	8	-0.000	-13.912	8	7	0.000	14.211	0.000	0.299
7	9	28.154	1.037	9	7	-28.154	-0.270	0.000	0.767
9	10	5.129	4.328	10	9	-5.116	-4.295	0.013	0.033
9	14	9.686	-12.506	14	9	-9.40	13.101	0.280	0.595
10	11	-3.884	-1.505	11	10	3.896	1.535	0.013	0.030
12	13	1.057	-3.009	13	12	-1.038	3.027	0.019	0.018
13	14	5.582	-5.362	14	13	-5.494	5.541	0.088	0.179
Total Loss								13.596	56.930

7. RESULTS AND ANALYSIS

We observe that for Example 1 where the network system IEEE 6 nodes in normal case (no non-linear loads), and after calculated the power flow in nodes and lines by the Newton- Raphson we obtain a value of 0.427MW for Power Losses in the lines, and a value of 1,226 MVar for losses of reactive power by cons if you place a SVC in the node 5, the losses of active power increases a range of 7.5 % and reactive power losses increase by a range of 5.3 % due to harmonic currents generated by the SVC.

For example 2 where the system of networks IEEE 14 Nodes, in normal case (not of nonlinear loads), and after the calculation of the flow of power in the nodes and the lines by the method Newton-Raphson one obtains a value of 13.593 MW for the losses of active power in the lines, and a value of 56.910 MVar for the losses of power reactivates, on the other hand if one places a SVC in the node 7, the losses of active power increase by a range of 0.3%, and the losses of reactive power increase by a range of 2.0%, due to the harmonic currents generate by the SVC. Depending on the location of the SVC in network systems have been studied. The results are acceptable when compared with the work [16, 17].

8. CONCLUSION

The HPFCODE program is called «Harmonics Power Flow CODE ", developed in MATLAB environment has been tested on several nonlinear loads such as: SVC, TCR, UPFC, and gaves entire satisfaction for the simulations performed confirming the relevance of this code. The results were almost consistent and show the influence of higher harmonics on power losses in electrical networks. And we have confirmed the possibility to analyze other nonlinear loads with this computer code HPFCODE generating harmonics in power systems.

On the basis of different nonlinear loads simulated on a number of different networks (IEEE 14nodes, IEEE 6nodes), which we consider fairly representative to validate our computer code, we can conclude that the computer code HPFCODE gives better results and can admit the improved graphical interface of this code, reducing the number of windows that are modifying it to simplify its use. Through the HPFCODE code, we can calculate the power flow of a power system with linear loads or with a nonlinear load any (SVC TCR, UPFC……), by the choice of a preferred network and the nonlinear load which we prefer, and running the program.

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BIOGRAPHIES OF AUTHORS

Aissa Souli, Researcher in Nuclear Research Center of Birine, PHD Student in Power System, Laghouat University- Algeria, e-mail:souliaissa@yahoo.fr

Profesor Abdelhafid Hellal, LACoSERE Laboratory, Electrical engineering Department, Laghouat University- Algeria, e-mail: a.hellal@mail.lagh-univ.dz