APÉNDICES

APÉNDICE I

Resultados obtenidos del sistema de 13 barras bajo la metodología NIHA

A continuación se presentan los resultados de la penetración armónica bajo la metodología NIHA en Matpower:

```
MATPOWER Version 5.1, 20-Mar-2015 -- AC Harmonic Power Flow Calculation
MATPOWER Version 5.1, 20-Mar-2015 -- AC Power Flow (Newton)
Newton's method power flow converged in 3 iterations.
Converged in 0.08 seconds
================================================================================
|     System Summary                                                           |
================================================================================
How many?                How much?              P (MW)            Q (MVAr)
---------------------    -------------------  -------------  -----------------
Buses             13     Total Gen Capacity     200.0           0.0 to 100.0
Generators         2     On-line Capacity       200.0           0.0 to 100.0
Committed Gens     2     Generation (actual)      9.4               2.4
Loads              7     Load                     9.3               7.6
  Fixed            7       Fixed                  9.3               7.6
  Dispatchable     0       Dispatchable        -0.0 of -0.0        -0.0
Shunts             1     Shunt (inj)             -0.0               5.9
Branches          12     Losses (I^2 * Z)         0.08              0.75
Transformers       7     Branch Charging (inj)     -                0.0
Inter-ties         0     Total Inter-tie Flow     0.0               0.0
Areas              1

                          Minimum                      Maximum
                 -------------------------  --------------------------------
Voltage Magnitude   0.979 p.u. @ bus 12         1.006 p.u. @ bus 13
Voltage Angle      -4.58 deg   @ bus 8          0.00 deg   @ bus 1
P Losses (I^2*R)             -                  0.02 MW    @ line 4-5
Q Losses (I^2*X)             -                  0.29 MVAr  @ line 4-5
```

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| Bus Data |

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Bus #	Voltage Mag(pu)	Voltage Ang(deg)	Generation P (MW)	Generation Q (MVAr)	Load P (MW)	Load Q (MVAr)
1	1.000	0.000*	7.36	0.54	-	-
2	0.995	-2.359	2.00	1.86	-	-
3	0.996	-3.446	-	-	0.60	0.53
4	0.999	-0.121	-	-	-	-
5	0.995	-2.370	-	-	2.24	2.00
6	0.994	-2.372	-	-	-	-
7	1.002	-4.566	-	-	1.15	0.29
8	1.001	-4.578	-	-	1.31	1.13
9	0.994	-2.368	-	-	-	-
10	0.984	-3.855	-	-	0.81	0.80
11	0.994	-2.367	-	-	-	-
12	0.979	-3.048	-	-	0.37	0.33
13	1.006	-4.430	-	-	2.80	2.50
		Total:	9.36	2.40	9.28	7.58

===

| Branch Data |

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Brnch #	From Bus	To Bus	From Bus Injection P (MW)	From Bus Injection Q (MVAr)	To Bus Injection P (MW)	To Bus Injection Q (MVAr)	Loss (I^2 * Z) P (MW)	Loss (I^2 * Z) Q (MVAr)
1	1	4	7.36	0.54	-7.35	-0.52	0.008	0.02
2	2	3	0.60	0.55	-0.60	-0.53	0.004	0.02
3	2	5	1.40	1.31	-1.40	-1.30	0.000	0.00
4	4	5	7.35	0.52	-7.33	-0.23	0.017	0.29
5	5	6	2.48	1.57	-2.48	-1.57	0.001	0.00
6	5	9	0.82	0.85	-0.82	-0.85	0.000	0.00
7	5	11	3.19	3.04	-3.19	-3.04	0.002	0.00
8	6	7	1.16	0.34	-1.15	-0.29	0.008	0.05
9	6	8	1.32	1.23	-1.31	-1.13	0.013	0.10
10	9	10	0.82	0.85	-0.81	-0.80	0.008	0.05
11	11	12	0.37	0.34	-0.37	-0.33	0.001	0.01
12	11	13	2.82	2.70	-2.80	-2.50	0.017	0.20
						Total:	0.080	0.75

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=======

| System Summary |

===
=======

	How many?
Buses	13
Generators	2
Committed Gens	2
Loads	7
Fixed	6
Dispatchable	0
Total NON_LOAD	1
Shunts	1
Branches	12
Transformers	7
Areas	1
Number bus NON_LOAD	7
harmonic (spectrum) Maximum	37

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| Bus Data |

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bus	V1(L-N)	V3(L-N)	V5(L-N)	V7(L-N)	THDv[%]
1	39837.2	0	42.5964	103.715	0.283155
2	7927.6	0	55.0037	133.912	1.83718
3	276.124	0	1.90449	4.60956	1.81673
4	39790.2	0	55.3526	134.75	0.368328
5	7923.69	0	56.8853	138.501	1.90107
6	7921.41	0	57.4411	138.624	1.90499
7	277.654	0	12.6249	11.6929	7.46203
8	2404.6	0	17.0598	40.3175	1.82954
9	7921.77	0	56.8673	138.448	1.90081
10	272.642	0	1.93559	4.66144	1.86163
11	7918.69	0	56.8361	138.351	1.90026
12	271.446	0	1.94388	4.72113	1.8921
13	1393.67	0	9.82627	23.511	1.83821

APÉNDICE II

Archivo caso13barras.m

A continuación se presenta la estructura "mpc" que almacena los datos del sistema de trece (13) barras para la solución de penetración armónica bajo la metodología IHA en Matpower:

```
function mpc = caso13barras
% Harmonic Power flow data A 13-Bus Balanced Industrial Distribution System
%   MATPOWER
%   Id: caso13barras.m
%% MATPOWER Case Format : Version 2
mpc.version = '2';

%%-----  Power Flow Data  -----%%
%% system MVA base
mpc.baseMVA = 10;

%% bus data
 %   bus_i   type    Pd    Qd     Gs    Bs   area    Vm      Va      baseKV   zone     Vmax    Vmin   nonl_load
mpc.bus = [
        1       3       0       0       0     0    1        1        0        69         1        1.05      0.95    0;
        2       2       0       0       0     0    1        1        0       13.8        2        1.05      0.95    0;
        3       1      0.6    0.53     0     0    1        1        0      0.48        4        1.05      0.95    0;
        4       1       0       0       0     0    1        1        0        69         1        1.05      0.95    0;
        5       1      2.24    2        0     6    1        1        0       13.8        3        1.05      0.95    0;
        6       1      0        0       0     0    1        1        0       13.8        3        1.05      0.95    0;
        7       1      0.049 0.082 0     0    1        1        0       0.40        5        1.05      0.95    1;
        8       1      1.31    1.13    0     0    1        1        0       4.16        6        1.05      0.95    0;
        9       1       0       0       0     0    1        1        0       13.8        3        1.05      0.95    0;
       10       1      0.81    0.8     0     0    1        1        0       0.48        7        1.05      0.95    0;
       11       1       0       0       0     0    1        1        0      13.8         3        1.05      0.95    0;
       12       1      0.37    0.33    0     0    1        1        0      0.48         8        1.05      0.95    0;
       13       1       2.8    2.5     0     0    1        1        0      2.4          9        1.05      0.95    0;
];
%% generator data
%   bus  Pg Qg  Qmax Qmin   Vg  mBase   status  Pmax    Pmin    Pc1 Pc2 Qc1min  Qc1max  Qc2min
Qc2max  ramp_agc    ramp_10  ramp_30  ramp_q   apf    Rg            Xg
mpc.gen = [
      1     0  0      50      0        1      10         1       100         0       0     0       0            0           0
0           0               0             0          0         0   0.00045   0.00990;
      2     2  0      50      0     0.995  10         1       100         0       0     0       0            0           0
0           0               0             0          0         0   0.00192   0.07168;
    ];
```

```
%% branch data
%   fbus   tbus   r         x         b   rateA  rateB  rateC  ratio  angle  status  angmin  angmax
mpc.branch = [
    1   4   0.00139   0.00296   0   150   0   0   0       0   1   -360   360;
    2   3   0.06391   0.37797   0   150   0   0   0.975   0   1   -360   360;
    2   5   0.00122   0.00243   0   150   0   0   0       0   1   -360   360;
    4   5   0.00313   0.05324   0   150   0   0   1       0   1   -360   360;
    5   6   0.00075   0.00063   0   150   0   0   0       0   1   -360   360;
    5   9   0.00157   0.00131   0   150   0   0   0       0   1   -360   360;
    5   11  0.00109   0.00091   0   150   0   0   0       0   1   -360   360;
    6   7   0.05918   0.35510   0   150   0   0   0.975   0   1   -360   360;
    6   8   0.04314   0.34514   0   150   0   0   0.95    0   1   -360   360;
    9   10  0.05829   0.37888   0   150   0   0   0.975   0   1   -360   360;
    11  12  0.05575   0.36240   0   150   0   0   1       0   1   -360   360;
    11  13  0.01218   0.14616   0   150   0   0   0.95    0   1   -360   360;
  ];
```

APÉNDICE III

Función runpfH2.m

A continuación se presenta el código en Matpower para la función *runpfH2*:

```
function [MVAbase, bus, gen, branch, success, et] = runpfH2(casedata, mpopt)

%%-----  initialize  -----

close all; clear all; clc;
% iacm: corriente medida
% vacm: voltaje medido
% PhVk, PhIk : fasores de voltaje y corriente (numeros complejos) medidos
Nh=100; %armonicos de voltaje
NLamp=1000; %numero  de lamparas

%% Declaraciones de constantes generales
fs=60;ws=2*pi*fs; % frecuencia
Ts=1/fs; % Periodo del fundamental
Ns=10000; % número de muestras
ts = linspace(0,Ts,Ns); % rango de simulación en el tiempo
Hmax=2*Nh-1; % número de armónicos y armónico máximo
Nmax=Hmax;
k1=(1:2:Hmax)'; % vector columna de armónicos

%% Definición de los nombres de los índices de las matrices bus, gen, branch
% 1   2     3      4         5          6                   7      8      9    10   11                 12    13    14
[PQ, PV, REF, NONE, BUS_I, BUS_TYPE, PD, QD, GS, BS, BUS_AREA, VM, VA, BASE_KV,...
   ZONE, VMAX, VMIN, NONL_LOAD, LAM_P, LAM_Q, MU_VMAX, MU_VMIN] = idx_busH;
%   15         16         17       18                     19          20          21                   22

[F_BUS, T_BUS, BR_R, BR_X, BR_B, RATE_A, RATE_B, RATE_C, ...
   TAP, SHIFT, BR_STATUS, PF, QF, PT, QT, MU_SF, MU_ST, ...
   ANGMIN, ANGMAX, MU_ANGMIN, MU_ANGMAX] = idx_brchH ;

[GEN_BUS, PG, QG, QMAX, QMIN, VG, MBASE, GEN_STATUS, PMAX, PMIN, ...
   MU_PMAX, MU_PMIN, MU_QMAX, MU_QMIN, PC1, PC2, QC1MIN, QC1MAX, ...
   QC2MIN, QC2MAX, RAMP_AGC, RAMP_10, RAMP_30, RAMP_Q, APF,RG, XG] = idx_genH;

%% Definición de argumentos
if nargin < 4
   solvedcase = '' ;              %% don't save solved case
   if nargin < 3
      fname = '' ;              %% don't print results to a file
      if nargin < 2
         mpopt = mpoption;       %% use default options
         if nargin < 1
```

```
            casedata = 'caso13barras'; %% default data file is 'case13paper.m'
          end
        end
    end
end

%% Leer datos
mpc = loadcase(casedata);

%% Conversion interna
mpc = ext2int(mpc);
[baseMVA, bus, gen, branch] = deal(mpc.baseMVA, mpc.bus, mpc.gen, mpc.branch);

%% Correr flujo de carga convencional
t0 = clock;
if mpopt.verbose > 0
    v = mpver('all');
    fprintf('\nMATPOWER Version %s, %s', v.Version, v.Date);
end

%% Formulación
fprintf(' -- AC Harmonic Power Flow Calculation \n');
[MVAbase, bus, gen, branch, success, et] = runpf(casedata) ;

if mpopt.verbose
        fprintf('\nHarmonics Power Flow through iterative harmonic analysis method (IHA)\n');
end

success = 1;
mpc.et = etime(clock, t0);
mpc.success = success;
et=mpc.et;
fd=1;

%% Fasor de voltajes fundamentales de barras
Vbusf=bus(:,VM);
PHVbusf=bus(:,VA)*pi/180;
PhVbusf=Vbusf.*exp(1j*PHVbusf);

%% Extraer datos de voltaje en barra con carga CFL
nonL=find(bus(:,NONL_LOAD)); % Se toma los números de las barras en donde están las cargas no
lineales
V1=bus(nonL,VM);
PHV1=bus(nonL,VA)*pi/180; % ángulo en radianes

%% voltaje inicial, solo fundamental en por unidad
PhVh=[V1*exp(1j*PHV1);zeros(Nh-1,1)];
Vh=abs(PhVh);
THDv1=norm(Vh(2:end))*100;

%% Primera iteración
[PhIh, ykk] =Currents_Phasor_CFL(PhVh,MVAbase,bus(nonL,BASE_KV),NLamp);
Ih=abs(PhIh);PHIh=angle(PhIh); % modulo y fase corriente simulada
```

```
%% Corriente inicial en función del tiempo de la corriente simulada
iacn=zeros(Ns,1);
for i=1:Ns
    iacn(i)=sqrt(2)*sum(Ih.*cos(k1.*ws*ts(i)+PHIh));
end

%% cantidades bases
Ibase_sys=1e3*MVAbase/(sqrt(3)*bus(nonL,BASE_KV));
Irms=norm(Ih)*Ibase_sys;

Vbase_nonL=bus(nonL,BASE_KV)*1e3;
Vrms1=norm(Vh)*Vbase_nonL;

%% lazo iterativo para determinar las tensiones armónicas de las barras
%% Tamaño de cosas
nb = size(bus, 1);      %% Numero de barras
nl = size(branch, 1);   %% Numero de ramas
ng = size(gen, 1);      %% Numero de generadores

E=1;
Vhar=zeros(nb,Nh);
Vharo(:,1)=PhVbusf;

while E>0.005

    for j=1:Nh; % vector de armónicos
        k=2*j-1;

        YbusH=makeYbusH_v3(baseMVA,bus,branch,gen,k) + …
                    sparse(nonL,nonL,ykk(j),nb,nb); % Matriz de admitancia armónica
        Ihar= -bus(:,NONL_LOAD).*PhIh(j); % vector de corrientes de barra
        Vhar(:,j)=YbusH\Ihar; % matriz de tensiones de barra
    end
        Vhar(:,1)=Vharo(:,1)+Vhar(:,1);

    THDv=sqrt(sum(abs(Vhar(nonL,2:end)).^2,2))./abs(Vhar(nonL,1))*100;
    E=abs(THDv-THDv1);
    [PhIh, ykk] =Currents_Phasor_CFL(Vhar(nonL,:).',MVAbase,bus(nonL,BASE_KV),NLamp);

    THDv1=THDv;
    Vharo(:,1)=Vhar(:,1);
end

%% Corriente considerando el voltaje distorsionado
Ih1=abs(PhIh);PHIh1=angle(PhIh); % modulo y fase de la corriente simulada con distorsión
Irms1=norm(Ih1)*Ibase_sys;

%% corriente final en función del tiempo de la corriente simulada
iacn=zeros(Ns,1);
for i=1:Ns
    iacn(i)=sqrt(2)*sum(Ih1.*cos(k1.*ws*ts(i)+PHIh1));
end
```

```
%% Tensión en función del tiempo
Vf=Vh;PHVf=angle(Vh); % modulo y fase de la tensión fundamental en la barra de carga no lineal
Vh7=abs(Vhar(nonL,:)).'; PHVh7=angle(Vhar(nonL,:)).'; % modulo y fase de la tensión distorsionada
en la barra de carga no lineal
Vbase_nonL=bus(nonL,BASE_KV)*1e3; %tensión base en la barra de carga no lineal
Vrms=norm(Vh7)*Vbase_nonL; % voltaje trifásico en kV

SnonL=sqrt(3)*Vrms*Irms1/1e3 % potencia aparente trifásica kVA
PnonL=sum(Vh7.*Ih1.*cos(PHVh7-PHIh1))*MVAbase*1e3 %potencia activa en kW
fp_nonL=PnonL/SnonL %factor de potencia
QnonL=sqrt(SnonL*SnonL-PnonL*PnonL) %potencia reactiva en kVar

vacn=zeros(Ns,1);
vacn1=zeros(Ns,1);
for i=1:Ns
    vacn1(i)=sqrt(2)*sum(Vf.*cos(k1.*ws*ts(i)+PHVf));
    vacn(i)=sqrt(2)*sum(Vh7.*cos(k1.*ws*ts(i)+PHVh7));
end

%% Gráficas
figure(1)
plot(ts*1e3,iacn*Ibase_sys,'b',ts*1e3,iacn1*Ibase_sys,'r')
legend('I_f_u_n_d','I_h_a_r_m',2);
title(['Irms_f_u_n_d = ',num2str(Irms), 'A','  Irms_h_a_r_m = ',num2str(Irms1), 'A'])
ylabel('Corriente (A)')
xlabel('Tiempo (ms)')
grid on

fk=Vbase_nonL/sqrt(3); % voltaje monofásico

figure(2)
plot(ts*1e3,vacn1*fk,'b',ts*1e3,vacn*fk,'r');
legend('V_f_u_n_d','V_h_a_r_m',4);
title(['Vrms_f_u_n_d = ',num2str(Vrms1/sqrt(3)), 'V','  Vrms_h_a_r_m = ',num2str(Vrms/sqrt(3)), 'V'])
ylabel('Tensión (V)')
xlabel('Tiempo (ms)')
grid on

%% Diagrama de tiempo y barras combinados
figure(40)
subplot(2,1,1)
plot(ts*1e3,iacn*Ibase_sys,'b');hold on
plot(ts*1e3,iacn1*Ibase_sys,'r');
legend('I_f_u_n_d','I_h_a_r_m',4);
title(['P_c_f_l = ',num2str(PnonL), 'kW','  S_c_f_l = ',num2str(SnonL), 'kVA','  fp_c_f_l =
',num2str(fp_nonL)])
ylabel('Corriente (A)')
xlabel('Tiempo (ms)')
grid on
subplot(2,1,2)
bar(k1,[Ih,Ih1]*Ibase_sys)
title(['Irms_f_u_n_d = ',num2str(Irms), 'A','   Irms_h_a_r_m = ',num2str(Irms1), 'A'])
legend('I_f_u_n_d','I_h_a_r_m',1);
```

```
xlabel('Armónico (h)')
ylabel('Amplitud (A)')
xlim([0 14])
ylim([0 110])
grid on

figure (50)
subplot(2,1,1)
plot(ts*1e3,vacn1*fk,'b',ts*1e3,vacn*fk,'r');
legend('V_f_u_n_d','V_h_a_r_m',4);
title(['Vrms_f_u_n_d = ',num2str(Vrms1/sqrt(3)), 'V','  Vrms_h_a_r_m = ',num2str(Vrms/sqrt(3)), 'V'])
ylabel('Tensión (V)')
xlabel('Tiempo (ms)')
grid on
subplot(2,1,2)
bar(k1,[Vf,Vh7]*fk)
title(['THD_v = ',num2str(THDv), '%'])
legend('V_f_u_n_d','V_h_a_r_m',1);
xlabel('Armónico (h)')
ylabel('Amplitud (V)')
xlim([2 51])
grid on

%% Importación del Fourier de corriente del ¨Pspice
%para la lámpara 2
filename = 'FourIlamp2.txt';
delimiterIn = ' ';
headerlinesIn = 4;
A = importdata(filename,delimiterIn,headerlinesIn);
MIpsp=A.data(1:2:end,3)/sqrt(2); % Valor rms de las amplitudes de corriente, armónicos impares

Irms2=norm(MIpsp);

r1=(1:2:15)';% rango armónico
figure(60)
bar(r1,[Ih1(1:8,1)*Ibase_sys,MIpsp])
title(['Irms_h_a_r_m = ',num2str(Irms1), 'A','   Irms_P_s_p_i_c_e = ',num2str(Irms2), 'A'])
legend('I_c_f_l_-_h_a_r_m','I_c_f_l_-_P_s_p_i_c_e',1);
xlabel('Armónico (h)')
ylabel('Amplitud (A)')
xlim([0 16])
ylim([0 110])
grid on

%% Importación de la onda de corriente del ¨Pspice
%para la lampara 2
filename = 'TimeIlamp2.txt';
%filename = 'TimeIlamp1.txt';
delimiterIn = ' ';
headerlinesIn = 13;
A = importdata(filename,delimiterIn,headerlinesIn);
ipsp=A.data(:,4);
 t1=linspace(0,20/1000,10000);
```

```
figure(70)
plot(ts*1e3,iacn1*Ibase_sys,'r');hold on
plot(t1*1e3,ipsp);
title(['Irms_h_a_r_m = ',num2str(Irms1), 'A','   Irms_P_s_p_i_c_e = ',num2str(Irms2), 'A'])
legend('I_c_f_l_-_h_a_r_m','I_c_f_l_-_P_s_p_i_c_e',2)
ylabel('Corriente (A)')
xlabel('Tiempo (ms)')
grid on

%% Determinación de la taza de distorsión de armónico THD
idx_paper=[1,4,5,2,3,6,7,8,9,11,12,13,10];
 abs(Vhar(idx_paper,1)).*bus(idx_paper,BASE_KV)/sqrt(3)*1000; % fundamental
 abs(Vhar(idx_paper,3)).*bus(idx_paper,BASE_KV)/sqrt(3)*1000; % 5 armonico
 abs(Vhar(idx_paper,4)).*bus(idx_paper,BASE_KV)/sqrt(3)*1000; % 7 armonico
 THDv = sqrt(sum(abs(Vhar(:,2:end)).^2,2))./abs(Vhar(:,1))*100; % Tasa distorsion
 THDv(idx_paper);
%% creación de un vector externo de los índices de las barras
i2e = bus(:, BUS_I) ;

% Parámetros
      g1=find(bus(:,NONL_LOAD));
%
      OUT_ALL         = mpopt.out.all;
      OUT_FORCE       = mpopt.out.force;
      SUPPRESS        = mpopt.out.suppress_detail;
%
 if SUPPRESS == -1
    if size(bus, 1) > 500
        SUPPRESS = 1;
    else
        SUPPRESS = 0;
    end
 end
      OUT_SYS_SUM     = OUT_ALL == 1 || (OUT_ALL == -1 && mpopt.out.sys_sum);
      OUT_BUS         = OUT_ALL == 1 || (OUT_ALL == -1 && ~SUPPRESS && mpopt.out.bus);
     % áreas
     xfmr = find(branch(:, TAP));                    %% indices of transformers
     nzld = find((bus(:, PD) | bus(:, QD)) & bus(:, BUS_TYPE) ~= NONE); % barras donde hay cargas
lineales
     sorted_areas = sort(bus(:, BUS_AREA)); % áreas del sistema
     s_areas = sorted_areas([1; find(diff(sorted_areas))+1]);    %% números de áreas
     nzsh = find((bus(:, GS) | bus(:, BS)) & bus(:, BUS_TYPE) ~= NONE); % barras donde hay
elementos shunt
     allg = find( ~isload(gen) ); % barras donde hay generación
     ong  = find( gen(:, GEN_STATUS) > 0 & ~isload(gen) );
     onld = find( gen(:, GEN_STATUS) > 0 &  isload(gen) );
%%  Resumen del sistema
if OUT_SYS_SUM && (success || OUT_FORCE)
     fprintf(fd,
'\n==========================================================================
=========');
     fprintf(fd, '\n|     System Summary                                                  |');
```

```
    fprintf(fd,
'\n===========================================================================
=========');
    fprintf(fd, '\n\n                   How many?                          ');
    fprintf(fd, '\n-------------------------------------------------------------     ');
    fprintf(fd, '\nBuses                %6d           ', nb);
    fprintf(fd, '\nGenerators           %6d         ', length(allg));
    fprintf(fd, '\nCommitted Gens        %5d     ', length(ong));
    fprintf(fd, '\nLoads                 %5d              ', length(nzld)+length(onld));
    fprintf(fd, '\n   Fixed              %5d          ', length(nzld)-sum(bus(:,NONL_LOAD)));
    fprintf(fd, '\n   Dispatchable        %5d      ', length(onld));
    fprintf(fd, '\n   Total NON_LOAD      %5d      ',sum(bus(:,NONL_LOAD)));
    fprintf(fd, '\nShunts                %5d     ', length(nzsh) );
    fprintf(fd, '\nBranches              %5d     ', nl );
    fprintf(fd, '\nTransformers           %5d    ', length(xfmr) );
    fprintf(fd, '\nAreas                 %5d', length(s_areas));
    fprintf(fd, '\nNumber bus NON_LOAD    %5d       ', g1);
    fprintf(fd, '\nMaximum');
    fprintf(fd, '\n--------------------------------');
 Vharm=zeros(nb,4);
for j=1:nb
    Vharm(j,1:4)=abs(Vhar(j,1:4))*bus(j,BASE_KV)/sqrt(3)*1000;
end
end
%% data de la barras- Tensiones armónicas
 if OUT_BUS && (success || OUT_FORCE)
     fprintf(fd,
'\n===========================================================================
===========================================================================
===========================================================================
===========================================================================
==');
   fprintf(fd, '\n|                           Bus Data
|');
   fprintf(fd,
'\n===========================================================================
===========================================================================
===========================================================================
===========================================================================
==\n');
   fprintf('   bus    ')
    for k=1:2:7
    fprintf(fd, ' V%d(L-N)  \t',k);
    end
   fprintf(fd,'   THDv[%%]\n')
   for j=1:nb
   fprintf(fd, '     %g\t',bus(j, BUS_I));
   fprintf(fd, '   %g   \t',Vharm(j,1:4));
   fprintf(fd, ' %g \t',THDv(j));
   fprintf(fd, ' \n');
   end
 end
end
```

APÉNDICE IV

Función Currents_Phasor_CFL.m

A continuación se presenta el código en Matpower para la función Currents_Phasor_CFL:

```
function [PhIh,ykk] =Currents_Phasor_CFL(PhVh,MVA_base,KV_base,NLamp)
% PhVh = fasor de voltajes armónicos = Vh*exp(j*PHVh) en pu
% Vh = amplitud del fasor PhVh = abs(PhHh)
% PHVh = fase del fasor PhVh
% Nk = número total de armónicos
% ws = frecuencia electrica
Nk=size(PhVh,1); %número de armónicos de tensión
Nh=Nk; %armónicos de corriente
fs=60; ws=2*pi*fs;
Kmax=2*Nk-1; % número de armónicos y armónico máximo
%Hmax=Kmax;
Hmax=2*Nh-1;

%% ------Lámpara a simular----------------------------------------------
Lamp=1;Type=3;archivo=1;
[RD,R,C]=ficheroDatosCFL(Lamp,Type,archivo);
rN=R/RD; XcN=1e6/(ws*C*RD);Xc=1e6/(ws*C);
%%----------------------------------------------------------------------
Nroh=7;
PhVh=[PhVh(1:Nroh);zeros(Nh-Nroh,1)]; % solo se consideran hasta el armónico 13 de voltaje
%% Voltaje y corriente rms, medidos--------------------------------------
VhN=PhVh; % Voltajes normalizado pu
%% Taza de distorsión armónica de voltaje----------------------------------
THDv = norm(VhN(2:end))*100;
%% Ángulos de conmutación------------------------------------------------
PHi=[-0.20    2.0]; % Valor inicial
PH=Funcion_PH(XcN,rN,VhN,Nk,PHi); % ángulo de conmutación simulados

%% Modelo de matrices Y--------------------------------------------------
if THDv <= 1
    [Yh,Ykk]=FunMatrixYA4(VhN,R,Xc,RD,PH,Kmax,Hmax);
elseif THDv >1 && THDv <= 4
    [Yh,Ykk]=FunMatrixYA3(VhN,R,Xc,RD,PH,Kmax,Hmax);
elseif THDv >4 && THDv <= 6
    [Yh,Ykk]=FunMatrixYA2(VhN,R,Xc,RD,PH,Kmax,Hmax);
elseif THDv >6 && THDv <= 8
    [Yh,Ykk]=FunMatrixYA1(VhN,R,Xc,RD,PH,Kmax,Hmax);
else
    [Yh,Ykk]=FunMatrixYF(VhN,R,Xc,RD,PH,Kmax,Hmax);
End
```

```
%% Valores base del sistema -------------------------------------------
Ibase_sys=1e3*MVA_base/(sqrt(3)*KV_base);
Zbase_sys=(1e3*KV_base/sqrt(3))/Ibase_sys;
%% Valores base del cfl ----------------------------------------------
Ibase_cfl=(1e3*KV_base/sqrt(3))/RD;
Zbase_cfl=RD;
%% Corriente armónica
PhIh=NLamp*Yh*PhVh; %corriente en pu
PhIh=PhIh*Ibase_cfl/Ibase_sys; % valor en pu base sys
%% admintacia propis
ykk=diag(Ykk);
ykk=ykk*1/Zbase_cfl; %admitancia en siemens
ykk=ykk/(1/Zbase_sys); % admitancia en pu base sys
ykk=NLamp*ykk;
end
```

APÉNDICE V

Resultados obtenidos del sistema de 13 barras bajo la metodología IHA

A continuación se presentan los resultados de la penetración armónica bajo la metodología IHA en Matpower:

- Caso 1: CFL – L1P11W

```
MATPOWER Version 5.1, 20-Mar-2015 -- AC Harmonic Power Flow Calculation
MATPOWER Version 5.1, 20-Mar-2015 -- AC Power Flow (Newton)
Newton's method power flow converged in 3 iterations.
Converged in 0.04 seconds
==========================================================================
=======
|     System Summary                                                   |
==========================================================================
=======
How many?                How much?       P (MW)       Q (MVAr)
---------------------          -------------------  -------------  -----------------
Buses                  13 Total Gen Capacity     200.0          0.0 to 100.0
Generators             2   On-line Capacity       200.0          0.0 to 100.0
Committed Gens   2    Generation (actual)      8.2              2.0
Loads                  7    Load                       8.2              7.4
Fixed                  7     Fixed                     8.2              7.4
Dispatchable       0     Dispatchable           -0.0 of -0.0   -0.0
Shunts                1    Shunt (inj)             -0.0              5.9
Branches            12   Losses (I^2 * Z)       0.06              0.61
Transformers       7    Branch Charging (inj)     -               0.0
Inter-ties            0    Total Inter-tie Flow     0.0              0.0
Areas                 1
                                 Minimum                Maximum
                         -------------------------  --------------------------------
Voltage Magnitude   0.980 p.u. @ bus 12        1.017 p.u. @ bus 7
Voltage Angle        -4.21 deg   @ bus 8         0.00 deg   @ bus 1
P Losses (I^2*R)                  -                   0.02 MW    @ line 11-13
Q Losses (I^2*X)                  -                   0.21 MVAr  @ line 4-5
```

==
=======
| Bus Data |
==
=======

Bus #	Voltage Mag(pu)	Voltage Ang(deg)	Generation P (MW)	Generation Q (MVAr)	Load P (MW)	Load Q (MVAr)
1	1.000	0.000*	6.24	0.57	-	-
2	0.995	-1.994	2.00	1.47	-	-
3	0.996	-3.081	-	-	0.60	0.53
4	0.999	-0.101	-	-	-	-
5	0.995	-2.007	-	-	2.24	2.00
6	0.994	-2.006	-	-	-	-
7	1.017	-2.082	-	-	0.05	0.07
8	1.001	-4.212	-	-	1.31	1.13
9	0.994	-2.005	-	-	-	-
10	0.984	-3.492	-	-	0.81	0.80
11	0.994	-2.685	-	-	-	-
12	0.980	-2.685	-	-	0.37	0.33
13	1.006	-4.067	-	-	2.80	2.50
		Total:	8.24	2.04	8.18	7.36

==
=======
| Branch Data |
==
=======

Brnch #	From Bus	To Bus	From Bus Injection P (MW)	From Bus Injection Q (MVAr)	To Bus Injection P (MW)	To Bus Injection Q (MVAr)	Loss (I^2 * Z) P (MW)	Loss (I^2 * Z) Q (MVAr)
1	1	4	6.24	0.57	-6.24	-0.55	0.005	0.01
2	2	3	0.60	0.55	-0.60	-0.53	0.004	0.02
3	2	5	1.40	0.91	-1.40	-0.91	0.000	0.00
4	4	5	6.24	0.55	-6.23	-0.35	0.012	0.21
5	5	6	1.37	1.30	-1.37	-1.30	0.000	0.00
6	5	9	0.82	0.85	-0.82	-0.85	0.000	0.00
7	5	11	3.19	3.04	-3.19	-3.04	0.002	0.00
8	6	7	0.05	0.07	-0.05	-0.07	0.000	0.00
9	6	8	1.32	1.23	-1.31	-1.13	0.013	0.10
10	9	10	0.82	0.85	-0.81	-0.80	0.008	0.05
11	11	12	0.37	0.34	-0.37	-0.33	0.001	0.01
12	11	13	2.82	2.70	-2.80	-2.50	0.017	0.20
						Total:	0.064	0.61

SnonL =
93.0128

PnonL =
47.1976

```
fp_nonL =
    0.5074

QnonL =
   80.1484

========================================================================
=======
|     System Summary                                    |
========================================================================
=======
                                How many?
---------------------------------------------------------------
Buses                               13
Generators                           2
Committed Gens                       2
Loads                                7
Fixed                                6
Dispatchable                         0
Total NON_LOAD                       1
Shunts                               1
Branches                            12
Transformers                         7
Areas                                1
Number bus NON_LOAD                  7
Maximum
---------------------------------
========================================================================
========================================================================
========================================================================
========================================================================
|                          Bus Data                                     |
========================================================================
========================================================================
========================================================================
========================================================================
```

bus	V1(L-N)	V3(L-N)	V5(L-N)	V7(L-N)	THDv[%]
1	39841.6	3.90779	8.78616	24.2485	0.0675322
2	7933.87	5.04674	11.3454	31.3085	0.437868
3	276.342	0.175434	0.392831	1.07771	0.432843
4	39799.7	5.08137	11.4173	31.5045	0.0878355
5	7930.59	5.21932	11.7335	32.3815	0.453062
6	7928.78	5.30164	11.8481	32.4101	0.453726
7	236.506	1.43414	2.17	2.27777	1.92289
8	2406.88	1.59755	3.51898	9.42669	0.435292
9	7928.67	5.21793	11.7298	32.369	0.452997
10	272.881	0.178919	0.399251	1.08986	0.443388
11	7925.59	5.21562	11.7233	32.3465	0.452862
12	271.683	0.178652	0.400956	1.1038	0.450856
13	1394.89	0.912443	2.02685	5.49698	0.437662

- Caso 2: CFL – L2P14W

```
MATPOWER Version 5.1, 20-Mar-2015 -- AC Harmonic Power Flow Calculation
MATPOWER Version 5.1, 20-Mar-2015 -- AC Power Flow (Newton)
Newton's method power flow converged in 3 iterations.
Converged in 0.05 seconds

================================================================================
|     System Summary                                                           |
================================================================================
How many?                How much?              P (MW)            Q (MVAr)
---------------------    -------------------  -------------  -----------------
Buses              13    Total Gen Capacity     200.0           0.0 to 100.0
Generators          2    On-line Capacity       200.0           0.0 to 100.0
Committed Gens      2    Generation (actual)      8.3               2.1
Loads               7    Load                     8.2               7.4
  Fixed             7      Fixed                  8.2               7.4
  Dispatchable      0      Dispatchable          -0.0 of -0.0      -0.0
Shunts              1    Shunt (inj)             -0.0               5.9
Branches           12    Losses (I^2 * Z)         0.06              0.62
Transformers        7    Branch Charging (inj)     -                0.0
Inter-ties          0    Total Inter-tie Flow     0.0               0.0
Areas               1

                          Minimum                      Maximum
                 -------------------------  --------------------------------
Voltage Magnitude   0.980 p.u. @ bus 12         1.017 p.u. @ bus 7
Voltage Angle      -4.22 deg   @ bus 8          0.00 deg   @ bus 1
P Losses (I^2*R)             -                  0.02 MW    @ line 11-13
Q Losses (I^2*X)             -                  0.21 MVAr  @ line 4-5


================================================================================
|     Bus Data                                                                 |
================================================================================
 Bus      Voltage          Generation             Load
  #   Mag(pu) Ang(deg)   P (MW)   Q (MVAr)   P (MW)   Q (MVAr)
----- ------- --------  --------  --------  --------  --------
    1  1.000    0.000*     6.26      0.57       -         -
    2  0.995   -1.998      2.00      1.49       -         -
    3  0.996   -3.085       -         -        0.60      0.53
    4  0.999   -0.102       -         -         -         -
    5  0.995   -2.011       -         -        2.24      2.00
    6  0.994   -2.011       -         -         -         -
    7  1.017   -2.107       -         -        0.06      0.08
    8  1.001   -4.216       -         -        1.31      1.13
    9  0.994   -2.010       -         -         -         -
   10  0.984   -3.496       -         -        0.81      0.80
   11  0.994   -2.009       -         -         -         -
   12  0.980   -2.690       -         -        0.37      0.33
```

13	1.006	-4.072	-	-	2.80	2.50
			--------	--------	--------	--------
		Total:	8.26	2.05	8.19	7.37

==
=======

| Branch Data |

==
=======

Brnch #	From Bus	To Bus	From Bus Injection P (MW)	Q (MVAr)	To Bus Injection P (MW)	Q (MVAr)	Loss (I^2 * Z) P (MW)	Q (MVAr)
-----	-----	-----	--------	--------	--------	--------	--------	--------
1	1	4	6.26	0.57	-6.25	-0.55	0.005	0.01
2	2	3	0.60	0.55	-0.60	-0.53	0.004	0.02
3	2	5	1.40	0.93	-1.40	-0.93	0.000	0.00
4	4	5	6.25	0.55	-6.24	-0.34	0.012	0.21
5	5	6	1.39	1.32	-1.39	-1.32	0.000	0.00
6	5	9	0.82	0.85	-0.82	-0.85	0.000	0.00
7	5	11	3.19	3.04	-3.19	-3.04	0.002	0.00
8	6	7	0.06	0.08	-0.06	-0.08	0.000	0.00
9	6	8	1.32	1.23	-1.31	-1.13	0.013	0.10
10	9	10	0.82	0.85	-0.81	-0.80	0.008	0.05
11	11	12	0.37	0.34	-0.37	-0.33	0.001	0.01
12	11	13	2.82	2.70	-2.80	-2.50	0.017	0.20
							--------	--------
						Total:	0.064	0.62

SnonL =

113.1107

PnonL =

60.8030

fp_nonL =

0.5376

QnonL =

95.3783

==
=======

| System Summary |

==
=======

	How many?
Buses	13
Generators	2
Committed Gens	2

Loads	7
Fixed	6
Dispatchable	0
Total NON_LOAD	1
Shunts	1
Branches	12
Transformers	7
Areas	1
Number bus NON_LOAD	7

Maximum

==
==
==
==

| Bus Data |

==
==
==
==

bus	V1(L-N)	V3(L-N)	V5(L-N)	V7(L-N)	THDv[%]
1	39841.4	5.04404	10.8839	26.6051	0.0744855
2	7933.52	6.51416	14.0542	34.3512	0.482974
3	276.33	0.226444	0.486623	1.18245	0.477668
4	39799.2	6.55885	14.1433	34.5663	0.0968809
5	7930.19	6.73692	14.5349	35.5286	0.499733
6	7928.35	6.84316	14.677	35.5599	0.500847
7	236.224	1.85114	2.68811	2.49915	2.08806
8	2406.75	2.06206	4.35916	10.3428	0.481315
9	7928.27	6.73512	14.5303	35.5148	0.499665
10	272.867	0.230942	0.494575	1.19578	0.489509
11	7925.18	6.73213	14.5224	35.4901	0.499522
12	271.669	0.230598	0.496688	1.21108	0.497405
13	1394.82	1.17775	2.51078	6.0312	0.483442

APÉNDICE VI

Ficheros de salida en PSpice

A continuación se presentan los ficheros que contienen los datos de salida de la simulación en PSpice.

- Componentes de Fourier para construir el diagrama de barras:

DC COMPONENT = 7.7401E-04

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	6.0000E+01	1.4418E+02	1.0000E+00	-1.6034E+02	0.0000E+00
2	1.2000E+02	1.5707E-02	1.0894E-04	-1.3617E+02	1.8452E+02
3	1.8000E+02	1.2927E+02	8.9655E-01	5.9428E+01	5.4046E+02
4	2.4000E+02	2.6107E-02	1.8107E-04	8.0932E+01	7.2231E+02
5	3.0000E+02	1.0365E+02	7.1886E-01	-7.9284E+01	7.2243E+02
6	3.6000E+02	2.8871E-02	2.0024E-04	-5.7266E+01	9.0480E+02
7	4.2000E+02	7.4175E+01	5.1446E-01	1.4506E+02	1.2675E+03
8	4.8000E+02	2.5422E-02	1.7632E-04	1.7041E+02	1.4532E+03
9	5.4000E+02	4.7855E+01	3.3191E-01	1.4798E+01	1.4579E+03
10	6.0000E+02	1.9855E-02	1.3771E-04	4.6136E+01	1.6496E+03
11	6.6000E+02	2.9231E+01	2.0274E-01	-1.0765E+02	1.6561E+03
12	7.2000E+02	1.5343E-02	1.0641E-04	-7.2238E+01	1.8519E+03
13	7.8000E+02	1.8334E+01	1.2716E-01	1.3626E+02	2.2207E+03
14	8.4000E+02	1.1446E-02	7.9386E-05	1.6955E+02	2.4144E+03
15	9.0000E+02	1.1555E+01	8.0139E-02	2.1589E+01	2.4267E+03

TOTAL HARMONIC DISTORTION = 1.3263E+02 PERCENT

- Valores en el dominio del tiempo para construir el gráfico de la forma de onda de la corriente en la carga no lineal (CFL):

TIME	V(1,0)	V(4,0)	I(Vdc)
5.000E-01	3.266E+02	3.305E+02	8.657E+01
5.000E-01	3.266E+02	3.305E+02	8.657E+01
5.000E-01	3.266E+02	3.305E+02	8.604E+01
5.000E-01	3.266E+02	3.305E+02	8.604E+01
5.000E-01	3.266E+02	3.304E+02	8.500E+01
5.000E-01	3.266E+02	3.304E+02	8.500E+01
5.000E-01	3.266E+02	3.304E+02	8.345E+01

5.000E-01	3.266E+02	3.304E+02	8.294E+01
5.000E-01	3.266E+02	3.304E+02	8.294E+01
5.000E-01	3.266E+02	3.304E+02	8.294E+01
5.000E-01	3.266E+02	3.303E+02	8.143E+01
5.000E-01	3.266E+02	3.303E+02	8.093E+01
5.000E-01	3.266E+02	3.303E+02	8.043E+01
5.000E-01	3.266E+02	3.303E+02	7.993E+01
5.000E-01	3.266E+02	3.302E+02	7.942E+01
5.000E-01	3.266E+02	3.302E+02	7.893E+01
5.000E-01	3.266E+02	3.302E+02	7.893E+01
5.000E-01	3.266E+02	3.302E+02	7.893E+01
5.000E-01	3.266E+02	3.302E+02	7.748E+01
5.000E-01	3.266E+02	3.301E+02	7.700E+01
	⋮		
5.200E-01	1.056E+02	1.056E+02	-1.001E-07
5.200E-01	1.054E+02	1.054E+02	-1.007E-07
5.200E-01	1.051E+02	1.051E+02	-1.013E-07
5.200E-01	1.049E+02	1.049E+02	-1.019E-07
5.200E-01	1.047E+02	1.047E+02	-1.026E-07
5.200E-01	1.046E+02	1.046E+02	-1.028E-07
5.200E-01	1.046E+02	1.046E+02	-1.028E-07
5.200E-01	1.040E+02	1.040E+02	-1.044E-07
5.200E-01	1.037E+02	1.037E+02	-1.050E-07
5.200E-01	1.035E+02	1.035E+02	-1.056E-07
5.200E-01	1.033E+02	1.033E+02	-1.062E-07
5.200E-01	1.030E+02	1.030E+02	-1.069E-07
5.200E-01	1.028E+02	1.028E+02	-1.075E-07
5.200E-01	1.026E+02	1.026E+02	-1.081E-07
5.200E-01	1.023E+02	1.023E+02	-1.087E-07
5.200E-01	1.022E+02	1.022E+02	-1.089E-07
5.200E-01	1.022E+02	1.022E+02	-1.089E-07
5.200E-01	1.016E+02	1.016E+02	-1.144E-07
5.200E-01	1.014E+02	1.014E+02	-1.165E-07
5.200E-01	1.012E+02	1.012E+02	-1.186E-07