7

ANEXOS

A continuación se expone:

- *El código fuente que integra el método de detección y la interfaz de usuario*
- *El artículo enviado al 15º Congreso Internacional de Metrología, 2011*

1. CÓDIGO FUENTE

interfaz.m

```
function varargout = interfaz(varargin)
%      INTERFAZ M-file for interfaz.fig
%      INTERFAZ, by itself, creates a new INTERFAZ or raises the existing
%      singleton*.
%
%      H = INTERFAZ returns the handle to a new INTERFAZ or the handle to
%      the existing singleton*.
%
%      INTERFAZ('Property','Value',...) creates a new INTERFAZ using the
%      given property value pairs. Unrecognized properties are passed via
%      varargin to interfaz_OpeningFcn.  This calling syntax produces a
%      warning when there is an existing singleton*.
%
%      INTERFAZ('CALLBACK') and INTERFAZ('CALLBACK',hObject,...) call the
%      local function named CALLBACK in INTERFAZ.M with the given input
%      arguments.
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help interfaz

% Last Modified by GUIDE v2.5 26-Feb-2011 12:42:43

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @interfaz_OpeningFcn, ...
                   'gui_OutputFcn',  @interfaz_OutputFcn, ...
                   'gui_LayoutFcn',  [], ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
  gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
   [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
   gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT


% --- Executes just before interfaz is made visible.
function interfaz_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   unrecognized PropertyName/PropertyValue pairs from the
%            command line (see VARARGIN)

% Choose default command line output for interfaz
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

 axes(handles.CIRCE);
```

```
uno=imread('db_circe.jpg');
uno=uint8(uno);
imshow(uno);

axis off

axes(handles.CEM)
dos=imread('logoCEM.jpg');
dos=uint8(dos);
imshow(dos);
axis off


 % UIWAIT makes interfaz wait for user response (see UIRESUME)
% uiwait(handles.figure1);


% --- Outputs from this function are returned to the command line.
function varargout = interfaz_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;


% --- Executes on button press in calcular.
function calcular_Callback(hObject, eventdata, handles)
% hObject    handle to calcular (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
global tension_1 frecuencia_1 profundidad_1 duracion_1...
      tension_2 frecuencia_2 tension_3 frecuencia_3...
      entrada resta2 perfil_rms tiempo_i_2 tiempo_f_2...
      rms_evento inicio_evento2  parte1 parte2...

%    frecuencias a inicio_evento2

  run calcula_eventos

  run detectar

  set(handles.comienzo_ideal,'String',tiempo_i_2);
  set(handles.final_ideal,'String',tiempo_f_2);
  durac = tiempo_f_2 - tiempo_i_2;
  set(handles.duracion_ideal,'String',durac);

  set(handles.comienzo_medido,'String',num2str(((inicio_evento2(2,1)-1)/12.8)));
  set(handles.final_medido,'String',num2str(((inicio_evento2(3,1)-1)/12.8)));

  diferencia = (inicio_evento2(3,1) - inicio_evento2(2,1))/12.8;
  set(handles.duracion_medida,'String',num2str(diferencia));

  us_diferencia = (diferencia - durac)*1000;
  set(handles.desviacion_duracion,'String',num2str(us_diferencia));

  valor_eficaz_true_antes = sqrt((tension_1^2)+(tension_2^2)+(tension_3^2));
  valor_eficaz_true_hueco = sqrt(((tension_1*((100-profundidad_1)/100))^2)+(tension_2^2)+(tension_3^2));
  profundidad_true = valor_eficaz_true_hueco*100/valor_eficaz_true_antes;
  porcent_true_hueco=rms_evento(15,2)*100/valor_eficaz_true_antes;

  diferencia_RMS=porcent_true_hueco-profundidad_true;

  porcent_true_hueco=sprintf('%2.3f',porcent_true_hueco);
  profundidad_true=sprintf('%2.3f',profundidad_true);
```

```
diferencia_RMS=sprintf('%2.3f',diferencia_RMS);

set(handles.profundidad_ideal,'String',profundidad_true);
set(handles.profundidad_medida,'String',porcent_true_hueco);
set(handles.desviacion_profundidad,'String',diferencia_RMS);


grid on

plot(handles.onda_entrada,entrada)

hold on
plot(handles.onda_entrada,perfil_rms,'r')
set(handles.onda_entrada,'Xlim',[0,2560],'FontSize',9);
axes(handles.onda_entrada);
xlabel ('Time*Fsample');
ylabel ('Voltage')

handles = guidata(hObject);
plot(handles.salida_filtro,resta2);%rms_evento
set(handles.salida_filtro,'Xlim',[0,2560],'FontSize',9);
grid on
axes(handles.salida_filtro);
xlabel ('Time*Fsample');
ylabel ('Voltage')
grid on
set(handles.calcular,'Visible','OFF');


% --- If Enable == 'on', executes on mouse press in 5 pixel border.
% --- Otherwise, executes on mouse press in 5 pixel border or over calcular.
function calcular_ButtonDownFcn(hObject, eventdata, handles)
% hObject    handle to calcular (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)


% --- Executes when selected object is changed in Parts.
function Parts_SelectionChangeFcn(hObject, eventdata, handles)
% hObject    handle to the selected object in Parts
% eventdata  structure with the following fields (see UIBUTTONGROUP)
%   EventName: string 'SelectionChanged' (read only)
%   OldValue: handle of the previously selected object or empty if none was selected
%   NewValue: handle of the currently selected object
% handles    structure with handles and user data (see GUIDATA)
switch get(eventdata.NewValue,'Tag')

   case 'Parte1'
      set(handles.duracion,'Visible','{ON}');
      set(handles.profundidad,'Visible','{ON}');
      limpia='';
      set(handles.tension,'String',limpia);
      set(handles.freq,'String',limpia);
      set(handles.profundidad,'String',limpia);
      set(handles.duracion,'String',limpia);

   otherwise

      limpia='';
      set(handles.tension,'String',limpia);
      set(handles.freq,'String',limpia);
      set(handles.profundidad,'String',limpia);
      set(handles.duracion,'String',limpia);
      set(handles.uipanel30,'Visible','OFF');
      set(handles.uipanel31,'Visible','OFF');
```

```
end


% --- Executes on button press in almacenar.
function almacenar_Callback(hObject, eventdata, handles)
% hObject    handle to almacenar (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
global tension_1 frecuencia_1 profundidad_1 duracion_1...
      tension_2 frecuencia_2 tension_3 frecuencia_3...
      comp1


h_selectedRadioButton=get(handles.Parts,'SelectedObject');
selectedRadioTag=get(h_selectedRadioButton,'Tag');

switch selectedRadioTag

   case 'Parte1'

      comp1=str2num(get(handles.tension,'String'));
      comp2=str2num(get(handles.freq,'String'));
      comp3=str2num(get(handles.duracion,'String'));
      comp4=str2num(get(handles.profundidad,'String'));

      if isempty(comp1)

         errordlg('Please, check the introduced RMS value','Input error')
         set(handles.uipanel2,'ForegroundColor',[0.8 0 0]);

      elseif isempty(comp2)

         errordlg('Please, check the introduced Frequency value','Input error')
         set(handles.uipanel3,'ForegroundColor',[0.8 0 0]);

      elseif isempty(comp3)

         errordlg('Please, check the introduced Duration value','Input error')
         set(handles.uipanel31,'ForegroundColor',[0.8 0 0]);

      elseif isempty(comp4)

         errordlg('Please, check the introduced Depth value','Input error')
         set(handles.uipanel30,'ForegroundColor',[0.8 0 0]);

      else

         tension_1=str2double(get(handles.tension,'String'));
         frecuencia_1=str2double(get(handles.freq,'String'));
         profundidad_1=str2double(get(handles.profundidad,'String'));
         duracion_1=str2double(get(handles.duracion,'String'));
         set(handles.Parte1,'Enable','OFF');

      end



   case 'Parte2'

         comp1=str2num(get(handles.tension,'String'));
         comp2=str2num(get(handles.freq,'String'));

      if isempty(comp1)

         errordlg('Please, check the introduced RMS value','Input error')
         set(handles.uipanel2,'ForegroundColor',[1 0 0]);
```

```
    elseif isempty(comp2)

        errordlg('Please, check the introduced Frequency value','Input error')
        set(handles.uipanel3,'ForegroundColor',[1 0 0]);

    else

        tension_2=str2double(get(handles.tension,'String'));
        frecuencia_2=str2double(get(handles.freq,'String'));
        set(handles.Parte2,'Enable','OFF');
    end


  case 'Parte3'

        comp1=str2num(get(handles.tension,'String'));
        comp2=str2num(get(handles.freq,'String'));

    if isempty(comp1)

        errordlg('Please, check the introduced RMS value','Input error')
        set(handles.uipanel2,'ForegroundColor',[1 0 0]);

    elseif isempty(comp2)

        errordlg('Please, check the introduced Frequency value','Input error')
        set(handles.uipanel3,'ForegroundColor',[1 0 0]);

    else

        tension_3=str2double(get(handles.tension,'String'));
        frecuencia_3=str2double(get(handles.freq,'String'));
        set(handles.Parte3,'Enable','OFF');
        set(handles.calcular,'Enable','ON');
        set(handles.almacenar,'Enable','OFF');
    end

end


 % --- Executes on button press in borrar.
function borrar_Callback(hObject, eventdata, handles)
% hObject    handle to borrar (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)


%       close(gcbf)
close all
clear all
interfaz


function edit23_Callback(hObject, eventdata, handles)
% hObject    handle to profundidad (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of profundidad as text
%       str2double(get(hObject,'String')) returns contents of profundidad as a double


% --- Executes during object creation, after setting all properties.
function edit23_CreateFcn(hObject, eventdata, handles)
% hObject    handle to profundidad (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
```

```
% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


 function profundidad_Callback(hObject, eventdata, handles)
% hObject    handle to profundidad (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of profundidad as text
%        str2double(get(hObject,'String')) returns contents of profundidad as a double


% --- Executes during object creation, after setting all properties.
function profundidad_CreateFcn(hObject, eventdata, handles)
% hObject    handle to profundidad (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes on button press in Parte1.
function Parte1_Callback(hObject, eventdata, handles)
% hObject    handle to Parte1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hint: get(hObject,'Value') returns toggle state of Parte1


 function tiempo_fin_Callback(hObject, eventdata, handles)
% hObject    handle to tension (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of tension as text
%        str2double(get(hObject,'String')) returns contents of tension as a double


% --- Executes during object creation, after setting all properties.
function tiempo_fin_CreateFcn(hObject, eventdata, handles)
% hObject    handle to tension (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


 function tension_Callback(hObject, eventdata, handles)
% hObject    handle to tension (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of tension as text
```

```
%        str2double(get(hObject,'String')) returns contents of tension as a double


% --- Executes during object creation, after setting all properties.
function tension_CreateFcn(hObject, eventdata, handles)
% hObject    handle to tension (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes during object creation, after setting all properties.
function duracion_CreateFcn(hObject, eventdata, handles)
% hObject    handle to duracion (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes during object creation, after setting all properties.
function freq_CreateFcn(hObject, eventdata, handles)
% hObject    handle to freq (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


 function freq_Callback(hObject, eventdata, handles)
% hObject    handle to freq (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of freq as text
%        str2double(get(hObject,'String')) returns contents of freq as a double
function duracion_Callback(hObject, eventdata, handles)
% hObject    handle to duracion (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of duracion as text
%        str2double(get(hObject,'String')) returns contents of duracion as a double
```

calcula_eventos.m

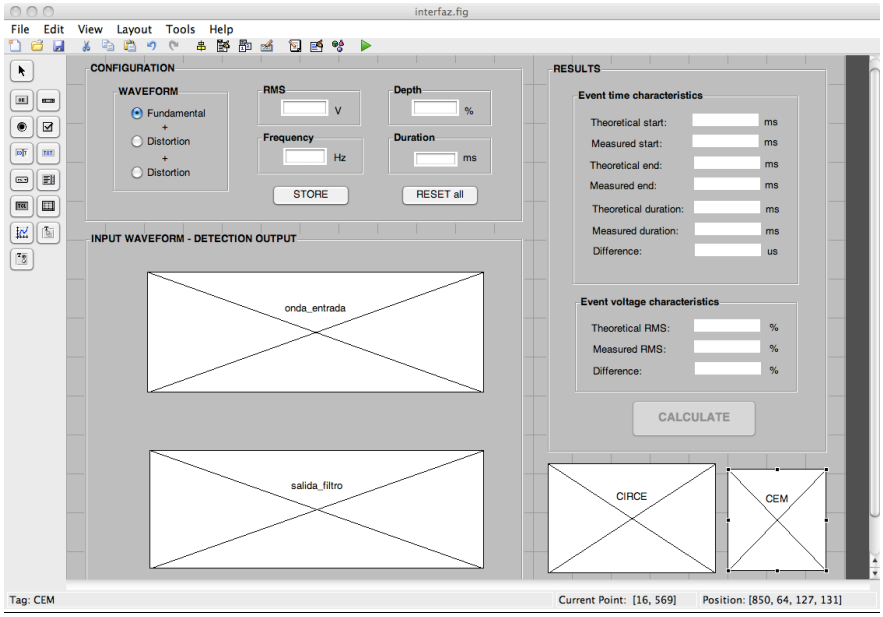
```
global nivel

tiempo=0.2; %segundos
Fsample=12800;
Fsamples=12800;
 frecuencia=50;
indice=1;
SNR=0; %El SNR viene en dB (db=20log10(K))

datos = Fsample * tiempo;

clear entrada
clear entrada2
entrada(datos)=0;

global tension_1 frecuencia_1 profundidad_1 duracion_1...

tension_2 frecuencia_2 tension_3 frecuencia_3 perfil_rms...
tiempo_i_2 tiempo_f_2 parte1
tiempo_i_2 = 100-(duracion_1/2);
tiempo_f_2 = 100+(duracion_1/2);
tiempo_i_1 = 0;
tiempo_f_1 = 200;
tiempo_i_4 = 0;
tiempo_f_4 = 200;
tiempo_i_5 = 0;
tiempo_f_5 = 200;

tension_armonico1 = tension_2;
tension_armonico2 = tension_3;
profundidad_2=profundidad_1;
profundidad_3=profundidad_1;

[parte1,rms_fund1]=amplitud_armonicos1(frecuencia_1, tiempo_i_1, tiempo_f_1, tension_1, tiempo_i_2,
tiempo_f_2, profundidad_1);
[parte4,rms_h1]=amplitud_armonicos2(frecuencia_2, tiempo_i_4, tiempo_f_4, tension_armonico1);
[parte5,rms_h2]=amplitud_armonicos2(frecuencia_3, tiempo_i_5, tiempo_f_5, tension_armonico2);

entrada = parte1 + parte4 + parte5;

perfil_rms = sqrt(rms_fund1.^2+rms_h1.^2+rms_h2.^2);

[duplicada]=duplicar(entrada);

nivel=1;

for i=1:1
   [LP,HP]=calculawavelet(duplicada);
   salida1LP(2*i-1,:)=LP;
   salida1HP(2*i-1,:)=HP;
end

a=salida1HP;

nivel=0;

entrada_norm=entrada/1000;

global elHi_Dno;
global elLo_Dno;

elHi_Dno = transpose (elHi_Dno);
entrada = transpose (entrada);
entrada_norm = transpose (entrada_norm);
```

detectar.m

```
global rms_evento inicio_evento2 resta2

modif=zeros(255,1);
modif2=cat(1,modif,entrada);
modif3=zeros(49,1);
modif4=cat(1,modif2,modif3);
resta=elHi_Dno(11:2894,1);
resta2=resta(256:2816,1);

modul=abs(resta2);

maximo = 1;


for j=1:20 %Antes ponÌa j=1:20

   for i=maximo+1:(length(resta2)-6)

      if modul(i,1) > modul(i-1,1) && modul(i,1) < modul(i+6,1) && modul(i,1) < modul(i+1,1) && modul(i,1) <
modul(i+2,1) && modul(i,1) < modul(i+3,1) && modul(i,1) > 1e-5
         inicio = i;
         parar = 0;
         break
      else
         parar = 1;
      end

   end


   if parar == 1
      break
   end


   valor_maximo = 0;

   for i=inicio:(length(resta2)-1)%Antes ponÌa i=inicio:(length(resta2))
      if modul(i,1) < modul(i+1,1) && modul(i+1,1) > valor_maximo
         valor_maximo = modul(i+1,1);
         maximo = i+1;
      end

      if modul(i,1) < valor_maximo*0.001
         final=i;
         break
      end
   end

   media=mean(resta2(inicio:final,1));
   desviacion=std(resta2(inicio:final,1));
   umbral=media+2.2*desviacion;
   [inicio_evento]=(find(resta2(inicio:final,1)>umbral)-1)+inicio;
variable=inicio_evento(1,1);
   inicio_evento2(j,1)=variable;

   clear variable
   clear inicio
   clear final

end

inicio_ventana = [1];
final_ventana = length(entrada);
```

```
inicio_evento2=cat(1,inicio_ventana,inicio_evento2);
inicio_evento2=cat(1,inicio_evento2,final_ventana);

for i=1:(length(inicio_evento2)-1)

   duracion = inicio_evento2(i+1) - inicio_evento2(i);

   if duracion >= 128

      evento = entrada (inicio_evento2(i):(inicio_evento2(i+1)-1),1);

      for k=1:(length(evento)-128) %128 data, 0.5 cycle (slidding window)

         rms_evento (k,i) = sqrt((1/128)*sum(evento(k:k+127).^2));

      end

      clear evento

   end

end
```

interfaz.fig



A NOVEL METHOD FOR VOLTAGE EVENT CHARACTERIZATION

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Abstract

Les méthodes actuelles pour analyser le point de départ de tout événement sont incapables de définir correctement ce genre de phénomènes avec une précision suffisante. Les méthodes basées sur le calcul RMS ont souvent des erreurs substantielles dans le temps et très dépendantes de la phase de la forme de l'onde de tension. En dépit de cet inconvénient précédent, ces méthodes sont utilisées dans la plupart des analyseurs de PQ.
Ce travail mettra au point une nouvelle méthode pour caractériser avec précision les paramètres qui définissent chaque événement (creux, surtension et interruptions), principalement la durée, l'instant initial et final, ainsi que la racine carrée moyenne durant la perturbation. La théorie d'ondelette sera utilisée dans le développement de la méthode.

The actual methods for analyzing the starting point of any event are unable to define properly this kind of phenomena with enough accuracy. Methods based on RMS calculation often have substantial errors in time and highly depend on the phase of the voltage waveform. In spite of this previous disadvantage, these methods are being used in most of the PQ analyzers.
This paper develops a novel method to characterize accurately the parameters that define each event (dips, swells and interruptions), mainly the duration, start and end instant as well as the root mean square during the disturbance. The wavelet theory will be used in the development of the method.

I. Introduction

According to EN 50160 standard [1], supply voltage events are characterized by two parameters: magnitude and duration. Regarding with magnitude, two voltage levels must be calculated:

- The depth of the voltage dip/interruption, defined as the difference between the reference voltage and the residual voltage often expressed as a value in volts or as a percentage or per unit value of the reference value. For swells, this difference is calculated from the maximum swell magnitude voltage and the reference voltage.
- The reference voltage, the value specified as the base on which the differences are expressed in per unit.

This magnitudes are normally measured using the following methods:

1. Root Mean Square calculation
2. Peak Value evaluation

Most measurement devices include the root mean square calculation algorithm for its simplicity and low calculation requirements. For these reasons, this method is proposed in power quality standards.

Time characterization is another important issue to be tracked during the event phenomena characterization. The duration is mainly determined by the operating time of protection relays or other devices used to clear the faults in the power system [2]. This parameter is obtained from the start and end values of the detection algorithm.

Paradoxically, the most adopted method (root mean square calculation) lacks of the necessary time sensitivity due to its dependency with the length of the measurement window. Besides, it does not provide accurate results of event start/end instants to quantify this kind of disturbance.

The application of the wavelet transform to power quality phenomena has recently experienced an important development [3,4,5]. This technique decomposes the signal into different parts corresponding to different bandwidths. It is the fastest method for event detection but the suitable wavelet filter must be previously selected.

The use of wavelet theory has allowed developing a more sensitive algorithm to sudden changes in amplitude. In this paper, a novel method, where duration and amplitude are obtained accurately, is proposed. Additionally, a Matlab-based interface has been developed to verify the correct design and operation of the algorithm.

II. Principles of measurement

Two different methods of characterizing voltage events are explained below.

Discrete RMS method

This method is based on the root mean square mathematical definition of a continuous waveform defined over the interval $t_1 \leq t \leq t_2$:

$$f(t)_{rms} = \sqrt{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}\left(f(t)\right)^2 dt} \qquad (1)$$

For *n* samples, its discrete form corresponds to:

$$rms = \sqrt{\frac{1}{n}\sum_{i=1}^{n} {x_i}^2} \qquad (2)$$

This method is usually defined for periodic waveforms, although it can also be used for non-periodic signals. The result of this procedure tightly depends on the length of the measurement window. The size can vary between

½ cycle (10 ms for a power frequency of 50 Hz) to any multiple of ½ cycle. According to the IEC 61000-4-30 [6], the value of the rms must be measured over 1 cycle, commencing at a fundamental zero crossing and refreshed each half-cycle.

With these considerations, the ideal rms (dotted green line) and the calculated $U_{rms(1/2)}$ (red line) are represented in Figure 1 for a voltage dip of 40%-magnitude and 40 ms-duration. The sampling rate was set to 36 kS/s.

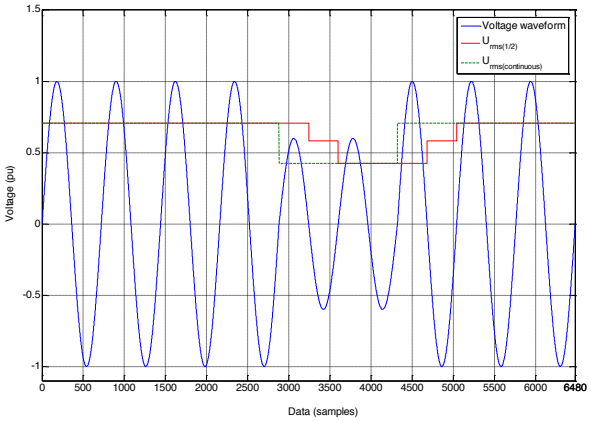

Figure 1. RMS detection comparative.

The results, shown in Figure 1, allow concluding that the $U_{rms(1/2)}$ method has an important delay due to the definition of the measurement window and its refreshing rate. According to the power quality standard, IEC 61000-4-30 [6], a new rms value is calculated every new ½ cycle (10 ms), giving important errors when short-duration events are evaluated.

To illustrate this issue, a new waveform was generated with a residual voltage of 60% and a duration of 16,08 ms as shown in Figure 2. The $U_{rms(1/2)}$ method is unable to accurately detect both, time and amplitude at the same time (note that the voltage dip does not remain a complete cycle).

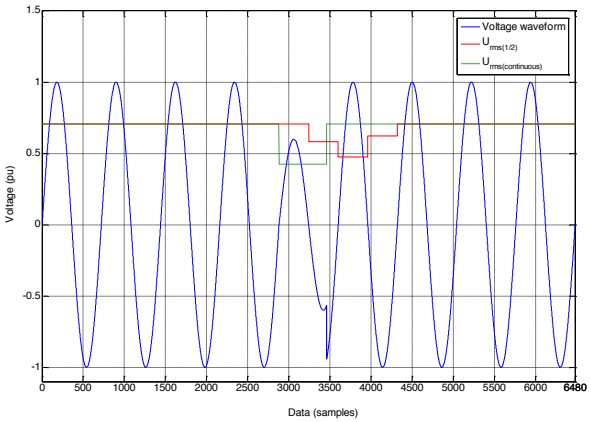

Figure 2. RMS detection comparative. Short-duration events

Additional tests, varying the event magnitude and duration, revealed excessive errors in the rms calculation (up to 65% from theoretical rms value) and duration evaluation (up to 50%).

It is clear that the $U_{rms(1/2)}$ method cannot be used to properly track sudden changes in voltage levels, giving inaccurate results when short-duration events must be analysed.

Wavelet transform method

The method is first based on the continuous wavelet transform. A wavelet ψ is a function of zero average:

$$\int_{-\infty}^{+\infty} \psi(t)\, dt = 0 \qquad (3)$$

which is stretched with a scale parameter *s*, and translated over the time by *u*, according to:

$$\psi_{u,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right) \qquad (4)$$

Substituting Eq.4 into Eq.3:

$$Wf(u,s) = \int_{-\infty}^{+\infty} f(t)\frac{1}{\sqrt{s}}\psi^*\left(\frac{t-u}{s}\right) dt \qquad (5)$$

Wavelet transform is used for time-frequency measurements, always according to the Heisenberg uncertainty principle [7]. When *s* varies, time and frequency spread are respectively proportional to *s* and 1/*s*, but maintaining its area constant.

While wider mathematical background of Wavelet Transform can be found in [8,9,10], the wavelet decomposition function is easily constructed using specific digital filters (discrete wavelet transform) for this particular implementation. The signal passes through a half band digital filter with impulse response (FIR or IIR). Filtering the signal is equal to apply the convolution operation to the input sequence with the response of the filter:

$$x[n] * h[n] = \sum_{k=-\infty}^{\infty} x[k] \cdot h[n-k] \qquad (6)$$

This method is very sensitive to slight changes in frequency content due to the filter impulse response. This property makes this method perfect for tracking voltage events.

III. Developed method - Tests

The model of the algorithm for event detection was implemented as follows. The input signal is convoluted with one specific digital filter. The chosen filter is an IIR Butterworth filter with 29 coefficients. The frequency rate of the system is 12.8 kS/s being the maximum time resolution:

$$\delta = \frac{1}{12.8\ kS/s} = 78.125\ \mu s \qquad (7)$$

The validity of the method was proofed varying the amplitude of the input wave from 0.95 pu to 0.05 pu. All the tests start at 100 ms (data=1281) and end at 120 ms (data=1537) as shown in Figure 3.

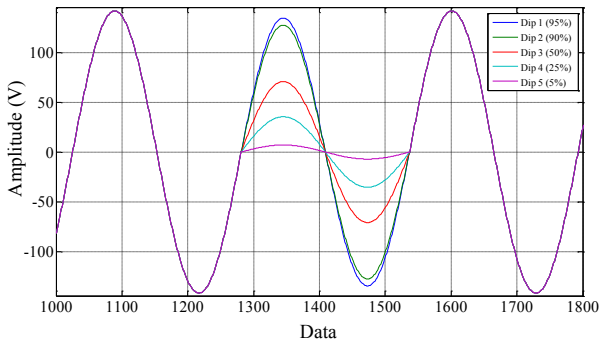

Figure 3. Event depth variations

The results obtained for the five previous tests show a constant detection delay regardless of the voltage variation as can be seen in Table 1.

Table 1. Event depth variation results

Event RMS	Event start (sample)	Event start detection (sample)	Event end (sample)	Event end detection (sample)
95,0 %	**1281**	1291	**1537**	1547
90,0 %	**1281**	1291	**1537**	1547
50,0 %	**1281**	1291	**1537**	1547
25,0 %	**1281**	1291	**1537**	1547
5,0 %	**1281**	1291	**1537**	1547

The influence of the relative start instant on the event detection time was also tested. Three different tests were carried out for event durations of 27.5 ms, 25 ms and 22.5 ms respectively, see Figure 4, finishing at the sample 1537 (time=120 ms).

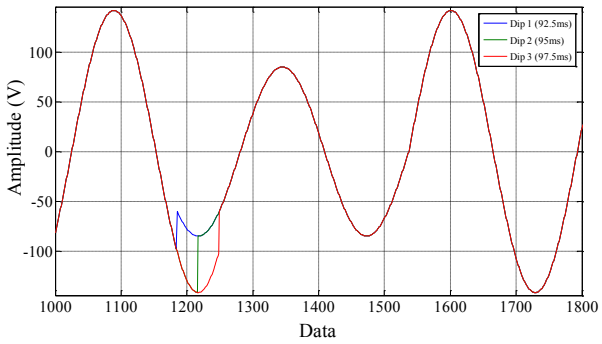

Figure 4. Event start variations

Once again, the analysis results showed the same delay for the three tested durations, 10 samples, as shown in Table 2.

Table 2. Event start variation results

Event duration	Event start (sample)	Event start detection (sample)	Event end (sample)	Event end detection (sample)
92,5 ms	**1185**	1195	**1537**	1547
95 ms	**1217**	1227	**1537**	1547
97,5 ms	**1249**	1259	**1537**	1547

The influence of phase jumps at the starting point of the event was also checked. Seven tests were performed with phase jumps varying from π/4 to 7π/4 for an event with a 60% of the reference voltage as shown in Figure 5.

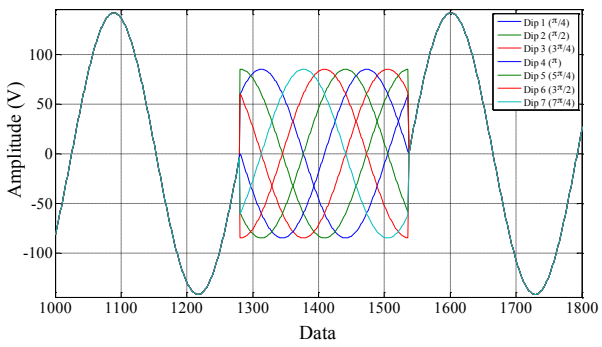

Figure 5. Phase jump variations

The results obtained are listed in Table 3.

Table 3. Phase jump variation results

Event phase at start	Event start (sample)	Event start detection (sample)	Event end (sample)	Event end detection (sample)
π/4	**1281**	1291	**1537**	1547
π /2	**1281**	1291	**1537**	1547
3π /4	**1281**	1291	**1537**	1547
π	**1281**	1291	**1537**	1547
5π /4	**1281**	1291	**1537**	1547
3π /2	**1281**	1291	**1537**	1547
7π /4	**1281**	1291	**1537**	1547

In contrast with simulated waveforms, real voltage signals have additional noise content. Wavelet coefficients are very sensitive to small changes so it is necessary to determine automatic trigger levels to avoid false detections. Therefore, the algorithm calculates the sliding threshold depending on the mean (μ) and the standard deviation (σ) of the samples around each local maximum (±10 samples):

$$Threshold = \mu + 3\sigma \qquad (8)$$

The algorithm automatically detects the voltage event when the filter output exceeds the calculated threshold. The rms is therefore calculated using (Eq.2).

With these premises, the three previous different test cases were the base to perform a precise adjustment of the method in terms of detection accuracy. The 10-sample offset due to the digital filter delay was corrected, giving exact time localization, within the used time resolution, for all the cases.

IV. Virtual Instrument Software Implementation

Matlab environment was selected to implement the detection algorithm. A user interface was developed with the GUI builder of Matlab to verify the design easier. To facilitate the realization of the work, the algorithm was previously checked with pure sinusoidal waveforms. Later, some additional frequency content was added. This interface allows the user to introduce one main component (voltage event) plus two different waveforms (additional harmonic content) to simulate real voltage disturbances.

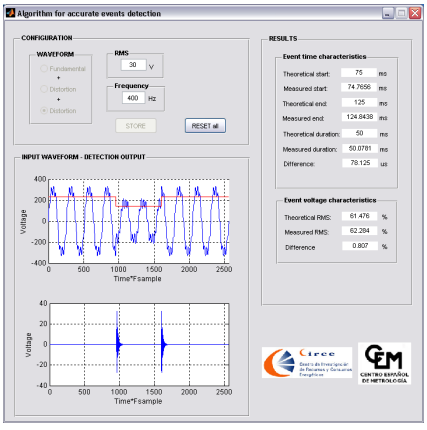

Figure 6. Event user interface

The interface shows the results for the following parameters:

- Theoretical start (ms)
- Measured start (ms)
- Theoretical end (ms)
- Measured end (ms)
- Theoretical duration (ms)
- Measured duration (ms)
- Difference (μs)
- Theoretical RMS (%)
- Measured RMS (%)
- Difference (%)

The composed waveform and its theoretical rms profile are depicted in the higher subplot while the output of the filter is represented underneath as shown in Figure 6. The voltage event is always centered within the time axis (x-axis) for the desired duration.

V. Test Results

To validate the feasibility of the proposed algorithm and the user interface, some different scenarios were evaluated. In Table 4, 10 test results were compiled for the verification of the implementation through the characterization of dips, swells and interruptions. The error between the theoretical rms and that from the algorithm were calculated as follows:

$$\varepsilon_{rms}(\%) = \frac{rms_{theoretical} - rms_{measured}}{rms_{theoretical}} \cdot 100 \qquad (9)$$

Δt was also calculated according to (Eq.10):

$$\Delta t(\mu s) = t_{theoretical}(\mu s) - t_{measured}(\mu s) \qquad (10)$$

being *t* the duration of the event.

Four different rms values for the fundamental waveform were considered (240 V, 230 V, 120 V and 110 V) at 50 Hz and 60 Hz. Additional frequency content was added to the fundamental wave to simulate real waveforms. These harmonic and interharmonic contents were varied from low frequencies (150 Hz) to higher orders (2500 Hz). The results showed that the accuracy of the proposed method is good enough for all the cases if they are compared with the $U_{rms(1/2)}$ method.

Table 4. Test results

	INPUT PARAMETERS								OUTPUT PARAMETERS		
	FUNDAMENTAL				1ST WAVEFORM		2ND WAVEFORM				
	Rms (V)	Frecuency (Hz)	Residual voltage (%)	Duration (ms)	Rms (V)	Frecuency (Hz)	Rms (V)	Frecuency (Hz)	Theoretical RMS [1] (%)	ε_{rms} (%)	Δt (μs)
1	230	50	30.0	40.00	15	200	25	500	32.310	-0.649	156.250
2	230	50	80.0	50.00	15	250	25	600	80.355	1.123	78.125
3	240	60	50.0	45.00	15	180	25	300	51.079	3.754	-78.125
4	230	50	60.0	89.10	—	—	—	—	60.000	0.000	40.625
5	230	50	0.0	60.00	—	—	—	—	0.000	0.000	156.250
6	230	50	3.0	64.00	—	—	—	—	3.000	0.000	140.625
7	120	60	30.0	63.01	50	150	20	250	49.249	0.965	36.875
8	120	60	0.2	40.00	10	150	—	—	8.307	-0.013	78.125
9	120	60	0.1	45.31	1	2500	2	150	1.866	-0.012	-75.625
10	110	60	40	12.00	5	250	10	1000	41.060	2.267	-46.87

[1] *Calculated with the combination of the Fundamental RMS during the event plus the 1st and 2nd waveform RMS*

VI. Conclusions

A novel method based on the Wavelet Transform was applied to characterize voltage dips, swells and interruptions. Due to the use of digital filters for analysing these kinds of phenomena, a constant delay was found and corrected. Later, a basic GUI was developed to have the configuration details and the algorithm information at a glance.

Results from the tested waveforms revealed a good behaviour of the method if compared with traditional detection implementations. The obtained overall time deviation was lower than 200 μs for all the cases while the calculated rms error does not exceed 4%. Therefore, the validity of the proposed method for voltage event detection can be considered good enough.

VII. Acknowledgements

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