Power Disturbance Classifier

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Abstract *— In this document we will analyze the voltage disturbance swells, sags and surge or spikes. Those are the most common power disturbances capable to cause malfunction or permanent damage in some equipment. The most common disturbances are the sag and surge which consist in a short duration drop in voltage. Those disturbances should be cause by Start-up of large appliances or faults on the electric delivery system caused by accidental damage, windy weather or lighting storm. To analyze those disturbances, we will created three matlab functions to model the sag, swell and surge. Those functions will analyze by using the wavelet function. By using the wavelet transform we will obtain the necessary figures that describe the voltage disturbances mentioned before. With those descriptions we can differentiate between voltage disturbances which allow us to classify them in three classes; sag, swell or surge. The signals will be simulated by using Matlab.*

Key Terms *— Sag, Surge, Swell, Wavelet Transform.*

INTRODUCTION

The sag is a short duration of drop in voltage. This disturbance should be cause by Start-up of large motors or momentary fault on the utility. The swell is the reverse form of Sag, having an increase in AC Voltage for duration of 0.5 cycles to 1 minute's time. This disturbance should be cause by high-impedance neutral connections, sudden large load reductions, and single-phase faults on a three phase system are common sources. The swells can cause data errors, light flickering, electrical contact degradation, and semiconductor damage in electronics causing hard server failures. The surge is a short-duration voltage spike in a voltage signal. Voltage spikes may be created by a rapid buildup or decay of a magnetic field, which may induce energy into the associated circuit. However voltage spikes can also have more mundane causes such as a fault in a transformer or higher-voltage (primary circuit) power wires falling onto lower-voltage (secondary circuit) power wires as a result of accident or storm damage.

VOLTAGE DISTURBANCE

Table 1 show all variables used in order to describe all voltage disturbance, (sag, swell and surge). The left side show the variables and in the right side the meaning.

Table 1
Function Variable

Variable	Description
s	Exponential Mgnitude
u_1	Start Time Step Function
u_2	End Time Step Function
f_1	Fundamental Frequency
f_r	Ripple Frequency
f_{osc}	Transient Oscillation Frequency
α	Sag Decay Rate
β	Sag Recovery Rate
ρ	Transient Ripple Rate
t	Fundamental Time 0< t < duration
t_1	Voltage Starting Time
t_2	Voltage End Time
t_m	Transient Magnitude
$e^{-i\omega t}$	Exponential Function
M_s	Voltage Induction Load Starting Function
M_r	Voltage Induction Load Recovery Function

Voltage Sag

Voltage sag is a momentary voltage drop in the range between 0.9pu to 0.1pu of the nominal voltage level, where (pu) means per unit. The pu is the expression of voltage quantities as fractions of a define base unit quantity. See Equation (1).

$$V_{pu} = \frac{V}{V_{base}} \qquad (1)$$

Typically the duration of this event is between .5 cycles to 1 min. There are two sources of voltage sags: external that is on the utility's lines by winding trees over power lines, lightning and internal causes by motors, grounding problem or wiring problems. Utilities continuously strive to provide the most reliable and consistent electric power possible. In the course of normal utility operations, however, many things can cause voltage sags. That's mean that the voltage sags are not stationary problem, can occurs from time to time.

The voltage sag can be modeled by sinusoidal function multiply by a step function. The mathematic formula is described as: [1], See Equation (2)

$$V_{sag} = [1 - s(u_1 - u_2)]\sin(2\pi f_1 t) \qquad (2)$$

Where the duration of the sag is determined by the step function $u_1 - u_2$, where u_1 is determine by t_1 and u_2 is determine by t_2, which is the start and end of the voltage sag. See Equation (3)

$$u_n = \begin{cases} 1: \forall_t \; if \; t - t_n > 0 \\ 0: \forall_t if \; t - t_n < 0 \end{cases} \qquad (3)$$

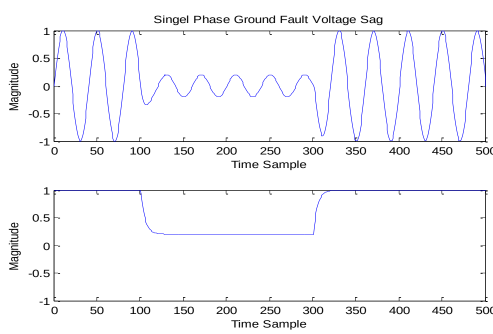

Figure 1
Matlab Ground Fault Sag Simulation

Figure 1 represent a dramatically Sag where the voltage decay up to 0.2 pu. caused by a ground fault. However, in distribution system, the voltage sag (2) looks similar, but typically the step function is to non-rectangular in shape.

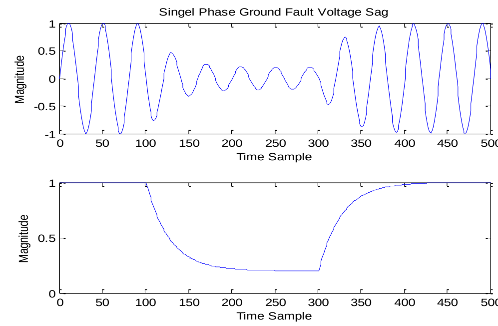

Figure 2
Power Fault Voltage Sag Simulation

If observed, the decay rate in the exponential function is most softly. This disturbance occurs when a large load or motor start. The mathematical formula describe as. [1],See Equation (4).

$$V_{sag} = \left[1 - s\left(u_1(1 - e^{-\alpha t_1})\right) - u_2(1 - e^{-\beta t_2})\right] \sin 2\pi f_1 t \qquad (4)$$

In matlab, we can model the sag disturbance creating by the convolution of $u_1\,(1 - e^{-\alpha t_1}) - u_2\left(1 - e^{-\beta t_2}\right)$, that represents the disturbance start and end time. The magnitude of the sag will be determined by the variable (s). See Figure (3).

```
f=60;
ts=1/(40*f);
n=512;
t=[0:n-1]*ts;
fsig=1*sin(2*pi*60*t);
figure
   ut1=100*ts;
   ut2=300*ts;
   step1 = t >= ut1;
   step2 = t >= ut2;
   ro1=90;
   ro2=90;
   s=0.8; %sag magnitude
   start=1-s.*(step1.*(1-exp(-ro1*(t-ut1)))); %start sag
   send=s.*step2.*(1-exp(-ro2*(t-ut2))); %end sag

   %%sum of step functions
   stse=[start+send];

   %%multiply step function by fundamental signal
   Vb=stse.*fsig;
```

Figure 3
This figure Represent the Matlab Code Used to Model the Sag Disturbance

Voltage Swell

Voltage Swell is defined by IEEE 1159 as the increase in the RMS voltage level to 1.1pu – 1.8pu of nominal voltage, at the power frequency for durations of ½ cycles to 1 minute. Voltage swell is consider less important as voltage sag, because is less common in distribution system. However, voltage swell has serious impact on equipment function. See Equation (5).

$$V_{sw} = [1 - s(-(u_1(1 - e^{-\alpha t_1})) - u_2(1 - e^{-\beta t_2}))]\sin(2\pi f_1 t) \qquad (5)$$

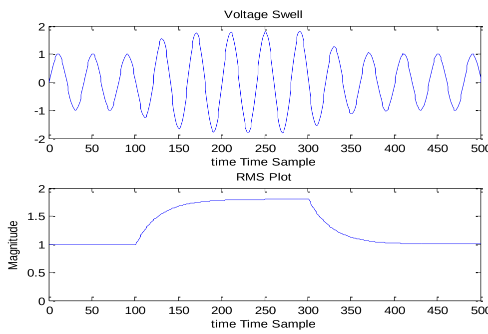

Figure 4
This is a Simulation of a Voltage Swell, with 5 Cycles of Duration

As well as the sag disturbance, to modeling the swell function is used the convolution of step functions. The difference between both is a negative sign, that is multiply by step functions. See Figure (5).

```
f=60;
ts=1/(40*f);
n=512;
t=[0:n-1]*ts;
fsig=1*sin(2*pi*60*t);
%%step function
  ut1=100*ts;
  ut2=300*ts;
  step1 = t >= ut1;
  step2 = t >= ut2;
  ro1=90;
  ro2=ro1;
  s=0.8; %sag magnitude
  start=1-s.*-1.*(step1.*(1-exp(-ro1*(t-ut1))));
  send=s.*step2.*-1.*(1-exp(-ro2*(t-ut2)));
  %%sum of step functions
  stse=[start+send];
  Va=stse.*fsig;
```

Figure 5
This Figure Represent the Matlab Code Used to Model the Swell Disturbance

Voltage Surge or Spike

The Voltage surge or spike is a very short duration disturbance reading on the sinusoidal waveform. Is not a stationary event, but can occur many times during a day by switching activities in the power distribution system. Transients are divided into two categories which are easy to identify: impulsive and oscillatory. If the mains signal is removed, the remaining waveform is the pure component of the transient. The transient is classified in the impulsive category when 77% of the peak-to-peak voltage of the pure component is of one polarity. Each category of transient is subdivided into three types related to the frequencies contained. Each type of transient can be associated with a group of phenomena occurring on the power system. In this project we will concentrate in the oscillatory category. [1]This disturbance can be modelating by using the following formula: See Equation (6).

$$V_s = \sin(2\pi f_1 t) + [u_1 * t_m \sin(2\pi f_{osc} t_1) * e^{-\rho t_1}] \qquad (6)$$

To model the surge, is necessary create a transient function, that represent the disturbance oscillation in the signal, Refer to “(6)”. This transient will be summed with the fundamental signal. See Figure (6).

```
n = 512;
fsignal = 60;
Ts = 1/(90*fsignal);
t = [0:n-1]*Ts;
%f = load_signal('Piece-Regular', n);
fclean = 1*sin(2*pi*fsignal*t);
% transient
  tm = 1;
  t1 =  120*Ts;
  fosc=400;
  ro = 300;
  ustep = (t >=t1);
  trans = ustep.*tm.*sin(2*pi*fosc*t).*exp(-ro*(t-t1));
  % Mix the clean and the transient
  fout= fclean+trans;
```

Figure 6
This Figure Represent the Matlab Code to Model the Surge Disturbance

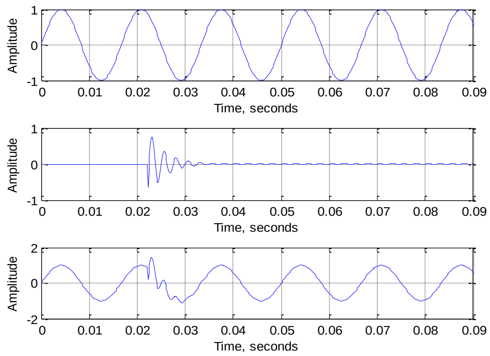

Figure 7

In this Figure Shows Three graph, Fundamental Signal, Transient and Signal Affected by a Surge Disturbance

Wavelet Coefficients

A wavelet is a mathematical function used to divide a given function or continuous- time signal into different scale components. Usually one can assign a frequency range to each scale component. Each scale component can then be studied with a resolution that matches its scale.

As a representation of a function by wavelets, the wavelets are scaled and translated copies (known as "daughter wavelets") of a finite-length or fast-decaying oscillating waveform (known as the "mother wavelet"). A mother wavelet is a function that oscillates, has finite energy and zero mean value. Compared with Fourier transform, wavelet can obtain both time and frequency information of signal, while only frequency information can be obtained by Fourier transform. The signal can be represented in terms of both the scaling and wavelet. [1] See Equation (7)

$$f_{(t)} = \sum_n C_j \varphi(t-n) + \sum_n \sum_{j=0}^{j-1} d_j(n) 2^{\frac{j}{2}} \psi(2^j t - n) \qquad (7)$$

Where,

- C_j = j level scaling coefficient
- d_j = j level of wavelet coefficient
- $\varphi(t)$ = Scaling function
- $\psi(t)$ = Wavelet function
- j = highest level wavelet transform
- t = time

The wavelet transform (Ψ) can be expressed as: See Equation (8).

$$\psi_{(f)} = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} \psi(\overline{\frac{x-b}{a}}) f_{(x)} dx \qquad (8)$$

Where,

- a = scale ($\Re$:)
- b = translation ($\Re$:)

Wavelets also can be used to extract information from many different kinds of data, including - but certainly not limited to - audio signals and images. Sets of wavelets are generally needed to analyze data fully.

A set of "complementary" wavelets will deconstruct data without gaps or overlap so that the deconstruction process is mathematically reversible. Thus, sets of complementary wavelets are useful in wavelet based compression /decompression algorithms where it is desirable to recover the original information with minimal loss.[2]

CONCLUSION

The power disturbances are momentary events that can occur one time as several times a day, that's why is difficult recognize what kind of event are and where come from. In order to recognize in a voltage signal all disturbance events, is necessary establish figures that describe each disturbance.

Due to the complexity of the analysis, we will use the wavelet to obtain the necessary figures that describe the disturbances. Using matlab as an analysis tool, will be modeled a clean sinusoidal signal. This signal will be compared with the same signal but affected by each voltage disturbance. This comparison will be made after apply the wavelet transform.

The wavelet coefficient will be used as figures in order to classify each disturbance in three classes; sag, swell and surge.

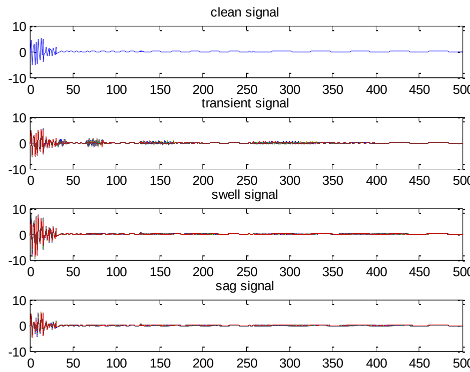

Figure 8
Simulation of Wavelet Function, in Which Include Clean Signal Transient Event, Swell Event and Sag Event

Figure 5 represent the wavelet coefficient. The first figure (clean signal) is a 60 Hz sinusoidal signal, the second (transient) is a 60 Hz sinusoidal signal affected by a surge event, the third (swell)) is a 60 Hz sinusoidal signal affected by a swell event and the fourth is a) is a 60 Hz sinusoidal signal affected by a swell event. The magnitudes of the signals are 1 pu.

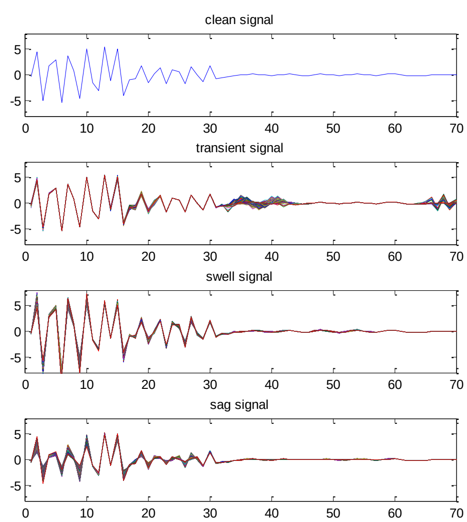

Figure 9
Zooming Disturbance Event Signals

In Figure 6, we can observe clearly the differences between the signals. That's means that should be possible insert those signals in a classifier for classify the signals in different classes; clean, sag, surge and swell, where the vectors will be the wavelet coefficients for each signal.

In Figure 10 shows the matlab program with the wavelet function added. The function call each signal function, (sag, swell and surge) and apply the wavelet transform to obtain the wavelet coefficient. See Figure 10.

```
n = 512;
fsignal = 60;
Ts = 1/(40*fsignal);
t = [0:n-1]*Ts;
%f = load_signal('Piece-Regular', n);
fclean = 1*sin(2*pi*fsignal*t);
 % transient
counter = 1;
for tinit = 1:150

   tm = 1;
   t1 =  tinit*Ts;
   fosc=400;
   ro = 300;
   ustep = (t >=t1);
   transient = ustep.*tm.*sin(2*pi*fosc*t).*exp(-
ro*(t-t1));
   %% Mix the clean and the transient
   fout(counter,:) = fclean+transient;
   subplot(3,1,3)
   plot(t,fout(counter,:));
   hold on;
   xlabel('Time, seconds');
   ylabel('Amplitude');
   grid on
   counter = counter+1;
end
%% 1D wavelet transform (you can use other
wavelet filters by looking at the 'options' field)
Jmin = 4; % minimum scale of the transform
%options.wavelet_type = 'daubechies';
options.wavelet_type = 'symmlet'
figure(2)
for counter=1:size(fout,1)
   fw_2(:,counter) =
perform_wavelet_transform(fout(counter,:).',Jmin,+
1,options); % computation of the transform until
scale Jmin
   % draw the original image
   %clf;
   subplot(2,1,1); plot(fout(counter,:)); hold on;axis
tight;
   title('Corrupted signal');
   hold on
   % draw the transformed coefficients (try to
understand their structure)
   subplot(2,1,2); plot(fw_2(:,counter)); axis tight;
```

```
   title('Wavelet coefficients');
end
%%swell function
[fswell,fw_3]=swell;

% draw the original image
%clf;
figure(3)
subplot(2,1,1); plot(fswell.'); axis tight;
title('Swell');
hold on
% draw the transformed coefficients (try to
understand their structure)
subplot(2,1,2); plot(fw_3); axis tight;
axis([0 100 -10 10])
title('Wavelet coefficients');

figure(4)
plot(fswell.')
%%sag_2 function
[fsag,fw_4]=sag_2;
figure(5)
subplot(2,1,1);
plot(fsag.');axis tight; title('Sag');
hold on
subplot(2,1,2);plot(fw_4);axis tight;axis([0 100 -10
10]);
%% 1D wavelet transform (you can use other
wavelet filters by looking at the 'options' field)
Jmin = 4; % minimum scale of the transform
%options.wavelet_type = 'daubechies';
options.wavelet_type = 'symmlet';
fw_1 =
perform_wavelet_transform(fclean.',Jmin,+1,option
s); % computation of the transform until scale Jmin
% draw the original image
%clf;
figure(4)
subplot(2,1,1); plot(fclean); axis tight;
title('Clean signal');
hold on
% draw the transformed coefficients (try to
understand their structure)
subplot(2,1,2); plot(fw_1); axis tight;
title('Wavelet coefficients')
%%Coefficients comparison
figure(8)
subplot(4,1,1),plot(fw_1),title('clean signal')
subplot(4,1,2),plot(fw_2),title('transient signal')
subplot(4,1,3),plot(fw_3),title('swell signal')
subplot(4,1,4),plot(fw_4),title('sag signal')
return
```

Figure 10
Matlab Program Code that Apply the Wavelet Function to Disturbed Signals

REFERENCE

[1] Rodney H.G. Tan, V.K. Ramachandaramurthy, “Numerical Model of Power Quality Events”, European Journal of Scientific Research, ISSN 1450-216X Vol. 43 No. 1, 2010, pp.30-47.

[2] Ricker, Norman. "WAVELET CONTRACTION, WAVELET EXPANSION AND THE CONTROL OF SEISMIC RESOLUTION". Geophysics 18 (4). doi:10.1190/1.1437927.

[3] http://en.wikipedia.org/wiki/Power_outage, “POWER OUTAGE”