A Novel Power Quality Index Using Discrete Wavelet Transform

Índice de Calidad de la Energía Usando Transformada Discreta de Wavelet

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ABSTRACT

In this work a general index of power quality (PQ) is proposed based on the simulation of some of the phenomena that affect the power quality. Using wavelet transform and calculating the energy coefficients to obtain a characteristic pattern of each signal to calculate the PQ index, using different wavelet functions. The proposed PQ index was compared with typical measurements phenomena under study.

Keywords: Power quality, wavelet, DWT, harmonics, sags, swells

RESUMEN

En este trabajo se propone un índice general de calidad de la energía (PQ), basado en la simulación de algunos de los fenómenos que afectan la forma de onda. Usando la transformada wavelet y el cálculo de los coeficientes de energía para obtener un patrón característico de cada señal para calcular el índice PQ, utilizando diferentes funciones wavelet. El índice PQ propuesto se comparó con mediciones fenómenos típicos en estudio.

Palabras clave: Calidad de la energía, wavelet, DWT, armónicos, sags, swells.

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I. INTRODUCTION

Power Quality received by the end user whether residential or industrial must be guaranteed for correct operation of the equipment and the system itself. However many phenomena, some inherent in the operation of the system, such as voltage variations due to the connection or disconnection of large loads and others produced by the same especially those with electronic components that introduce harmonics to the network, which distorts the wave. Each of these phenomena has different ways of being together making it difficult quantified comparison between one and one for identifying which affects the signal.

There have been some studies in which rates have been proposed for classifying and quantifying the effects from some phenomena that affect the power quality, for example:

In [3] a review of the application of signal processing, smart techniques and optimization techniques in the analysis of PQ is. Intelligent techniques such as fuzzy logic, neural networks and genetic algorithms and their fusion are reviewed. The authors suggest this work as a guide for deeper knowledge of the power quality.

[1] Propose an index of PQ based on discrete wavelet transform (DWT) is proposed to determine the amount of deviation of the pure desired signal. The proposed PQ index is defined as the weighted sum of percentage energy deviation of the details DWT.

[2] Propose an index that quantifies the deviation between the control voltage or current and the ideal voltage or current; this index can also be used for detection, quantification and classification of the severity of any disturbance. The index can be applied to variation in steady state and transient events. In the first case, the index is used to quantify the severity of the variation; in the latter case the index can be used for activation and event detection, but also to quantify its severity

In [4] an indicator of power quality that works using the wavelet transform, for which different functions are used bases and orders, and then determine which performs best to be compared with rates already proposed known.

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II. Power Quality Affectations

The study of the Power Quality is the first and most important step to identify and to solve problems of the power system. The affectation to the power systems can include damage the equipments and persons also the reduction of its performance, reliability, productivity and profitability (Saucedo & Texis, 2008)

A. Harmonic

Harmonics are sinusoidal voltages or currents whose frequency is an integer multiple value in which the system is designed for (fundamental frequency, typically 50 or 60 Hz) A harmonic signal can be represented by (1).

$$y(t) = Y_0 + \sum_{n=1}^{\infty} Y_n \sqrt{2}\, sen(n\omega - \varphi_n) \qquad (1)$$

Where:

Y_0: The amplitude of the DC component, which is usually zero in a stable state.

Y_n: The rms value of the component of n rank.

φ_n: It is the gap of the harmonic component.

B. *Sag and Swell*

Sags and swells are similar phenomena; the first corresponds to a decrease in signal amplitude between 0.1 and 0.9 in pu, while the second goes to an increase between 1.1 and 1.8 in pu.

III. Simulation

Simulations are used for obtaining the signals for all the phenomena to be analyzed, in Fig. 1, 2, 3 and 4 are shown as an example of each of the signals used in this study.

To simulate the harmonics, use the IEC 61000-3-6 for the delineation of each component will be considered. An example of signal containing harmonics is shown in Fig. 1.

The simulated swell and sags phenomena, which set are the generation code, the duration of these at a random, more therefore variation ranges magnitude are set unit according to the above mentioned. In this way is presented in Fig. 2 and Fig. 3 sags and swells signals respectively.

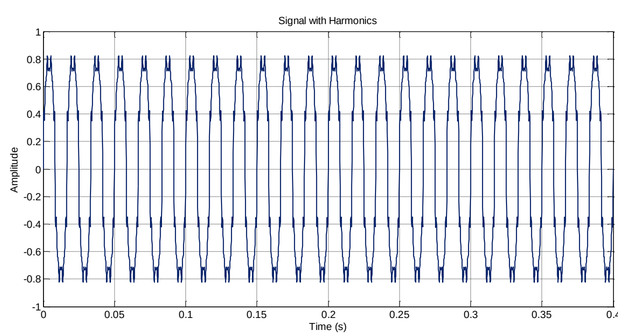

Figure 1. Signals with harmonics

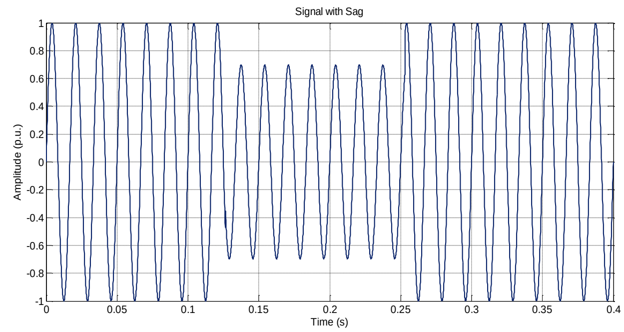

Figure 2. Signals with sags

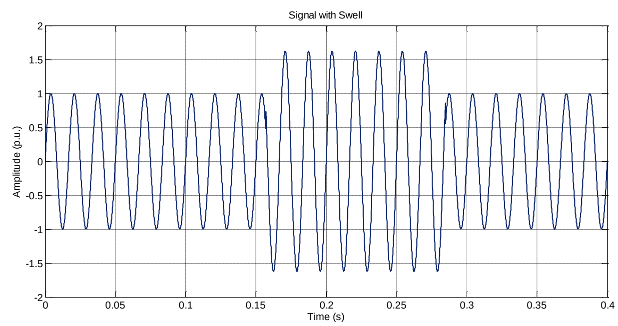

Figure 3. Signals with swell.

IV. Wavelet Transform

Is possible to analyze a signal in time and frequency using a technique called *Multiresolution Analysis*, this shows the signal at different frequencies with different resolutions [14], the main advantage of this analysis is the possibility of obtaining good time resolution but poor resolution at high frequencies and likewise, good resolution for low frequencies but poor resolution for time.

This is the benefit of wavelet transform, representing most advantage over the windowed Fourier transform, in which the entire signal is analyzed in the same selected window while the wavelet transform is discussed with variable resolution [15].

This analysis is based on obtaining the spectral components of signal amplitudes as a series of special functions, which are called *wavelets*. According Subhais Saha [16]: "*Wavelets are functions defined on finite intervals having an average value of zero*". It is necessary that the set of functions are used to form a base, which means that any signal has a unique decomposition and then reversing this decomposition can obtain the original signal [17].

The continuous wavelet transform is mathematically represented as (2):

$$C(\tau, s) = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{+\infty} f(t)\, \Psi\left[\frac{t-\tau}{s}\right] dt \qquad (2)$$

Where,

$$\Psi(\tau, s) = \frac{1}{\sqrt{|s|}} \Psi\left[\frac{t-\tau}{s}\right] \qquad (3)$$

Thus, $C(\tau, s)$ are the coefficients of *f(t)* in the space defined by the function $\Psi(\tau, s)$, a term which is called mother wavelet as it refers to a window function of finite length and oscillatory nature, presenting a prototype from which a group of window functions was generated [15].

Case for the discrete wavelet transform is defined by:

$$C[j,k] = \sum_{n \in Z} f[n]\Psi_{j,k}[n] \quad (4)$$

Where the mother wavelet is

$$\Psi_{j,k}[n] = 2^{-j/2}\Psi\left[2^{-j}n - k\right], \quad j,k \in Z \quad (5)$$

The parameters τ, s are defined as the dyadic scale, i.e., 2^n powers, so that $\tau = 2^j k$ and $s = 2^j$ [16]

That is, the wavelet transform will be to multiply the signal of study (*f*[*n*]), by the wavelet at each scale *j* while the latter runs through the time axis. The process is repeated but with different scales until the desired number of bands or scales is obtained [14].

The analysis can be interpreted as a measure of the similarity between the bases functions ($\Psi_{j,k}[n]$) and study the signal (*f* [*n*]), in its frequency content, therefore, the estimated coefficients (*C*[*j*, *k*]) indicating which so next is the signal to the wavelet in a specific scale.

Figure 5 shows the process of subband coding or multi-resolution using the H and G filters and a decimated by 2, the result of the high pass filter for filtering each level corresponds to a level of detail or wavelet coefficients. The result of each low pass filter is called level of approximation. Thus can be seen details of the signal in the frequency band required [17].

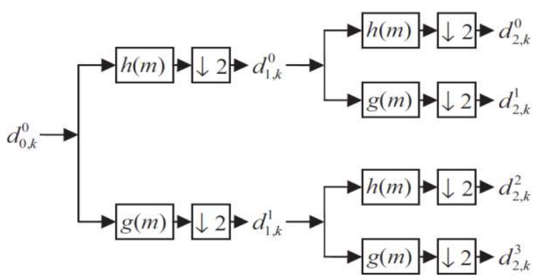

Figure 5. Two levels wavelet decomposition tree [14].

V. Methodology

One of the main advantages of using the wavelet transform is that this allows to decompose the signal into different detail coefficients which in turn allow to obtain information that can identify, classify and measure the original signal.

For the case study apply the wavelet transform to determine the first 10 coefficients detail signals with different perturbations, to subsequently calculate the energy of each level of these, this process is repeated for different wavelet mothers, so that subsequently can calculate the deviation of energy, as shown in (7):

$$Ed(j)\% = \left[\frac{En_{dist(j)} - En_{ref(j)}}{En_{ref(7)}}\right].100 \quad (7)$$

VI. Power Quality Indexes

In references [14] and [18] an analysis of different PQ indexes measuring some distortion of the waveform occurs, however these values is not only possible to establish which of these phenomena most affects the quality of the signal, and for example, while sags and swells has parameters such as the distortion duration and amplitude and for harmonics phenomena has the Total Harmonic Distortion (THD), if these values are compared is not possible to establish what signal is most affected.

A. Harmonics

The primary indicator to measure the harmonics is THD or simply THD, which can be calculated by the following equation (8): [19]

$$THD = \frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{I_1} \cdot 100\% \quad (8)$$

Where:
I_1: Amplitude of the fundamental wave.
I_k: Amplitude of harmonic *k*.

B. Sags and swells

According to references [13] and [18] the sag and swell characteristic parameters are shown in Figure 10, which ΔT represents the duration of the fall or rise, while ΔU is representing its the depth.

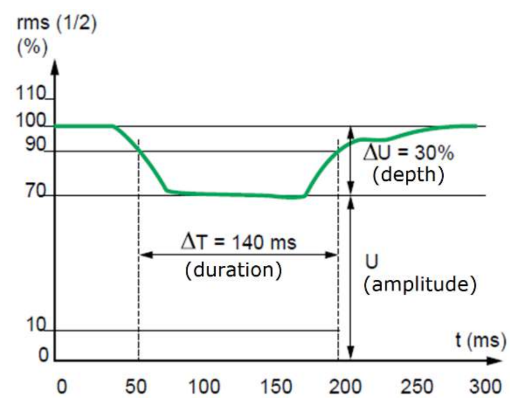

Figure 10. Sags y swells definition [20].

VII. Proposed Power Quality Index

According to the number of indexes for each of the phenomena under study, the need to present a general PQ index to evaluate and compare these distortions was observed.

Analyzing the preceding figures can easily find that every phenomenon has a singular characteristic pattern that allows easy identification, also can appreciate the differences in values for the distributions of individual energy, so, it is clear that calculating the total energy distribution of the first 10 detail coefficients of the wavelet transform can obtain a value that characterizes the magnitude of the disturbance.

The reference value to compare the effect on the signal is of course pure sine wave, which present a constant energy distribution of zero (0) for all coefficients. Using the following equation can be calculated the proposed PQ index; the sum of the absolute value of the energy distribution for each coefficient is used and normalized by dividing the result by the total number of coefficients in the study.

Thus (9) defines the PQ index.

$$PQ\_Index = \frac{\sum_{i=1}^{n} \left| E_{coef_i} \right|}{n} \quad (9)$$

Where:
$E_{coef\,i}$: Energy of the detail coefficient *i*.
n: Total number of detail coefficients.

VIII. Results

According to the provisions of the methodology, the detail coefficients and their respective energy for different wavelets are calculated as follows:

A. First case: Signal with harmonics.

Table 1 PQ_Index for Signal with Harmonics using different wavelets.

Signal	THD	PQ_Index				
		Db1	Db3	Db5	Db7	Db10
1	30,17	1543,232	134,428	45,065	50,618	26,334
2	3,05	18,393	16,190	2,119	2,915	1,598
3	2,71	17,905	12,518	0,897	4,054	2,212
4	12,97	394,895	64,240	19,121	14,633	14,894
5	8,02	127,363	41,089	7,275	11,027	8,785
6	13,70	399,652	69,980	18,074	15,881	15,230
7	9,83	194,349	50,887	9,529	11,015	8,575
8	10,78	219,615	54,317	9,053	14,780	11,872
9	6,02	85,399	30,346	7,693	6,351	5,756
10	10,45	202,511	52,971	7,997	12,377	8,950

According to Table 1 can be seen at a glance that the PQ_Index calculated with wavelet Db1 has greater difference from the THD calculated for each signal, however in Table 2 calculation error occurs

Table 2 Percentage difference for power quality indices for signal with Harmonics

Signal	% Error_Harmonics				
	Db1	Db3	Db5	Db7	Db10
1	5015,06	345,56	49,37	67,77	12,72
2	503,76	431,45	30,44	4,30	47,56
3	559,74	361,26	66,94	49,38	18,51
4	2945,29	395,40	47,46	12,85	14,86
5	1488,97	412,62	9,24	37,57	9,60
6	2818,11	410,97	31,97	15,96	11,21
7	1878,08	417,93	3,02	12,11	12,72
8	1936,46	403,67	16,05	37,06	10,08
9	1317,47	403,68	27,68	5,41	4,47
10	1838,35	407,01	23,45	18,47	14,33
Avarage	2030,13	398,95	30,56	26,09	**15,61**

As Table 2 shows that the Db10 has the lowest average error between proposed PQ_Index and THD calculated for each signal.

B. Second case: Signal with sags

In the case of signals with the particularity that sags have two reference values for measuring the magnitude of the event, in this case, duration and variation in the amplitude of the wave is observed. In this case the proposed index takes into account the combined effect of both references.

Table 3 shows the calculated values for 10 different signals affected by sags

Table 3 PQ_Index for Signal with Sags using different Wavelets.

Signal	ΔT	ΔU	PQ_Index				
			Db1	Db3	Db5	Db7	Db10
1	50	0,58	481,203	40,041	17,946	17,510	16,678
2	368	0,34	326,030	145,427	64,189	36,641	37,625
3	349	0,74	918,091	324,026	135,977	73,252	79,835
4	281	0,45	761,798	151,140	67,019	38,103	39,485
5	131	0,64	664,547	112,644	50,418	28,365	29,054
6	154	0,28	375,401	48,726	24,646	16,721	17,419
7	234	0,11	112,613	28,072	12,971	7,884	7,703
8	150	0,03	41,728	4,745	2,193	1,332	1,293
9	414	0,89	247,879	458,764	186,637	95,955	109,430
10	136	0,25	324,110	37,908	18,421	13,237	15,831

Table 4 shows the errors between the PQ_Index and reference values for sags shown, you can see that in this case the Db7 wavelet has better results, however the Db10, presents a similar error percentage.

Table 4 Percentage difference for power quality indices for signal with sags

Signal	% Error_Sag				
	Db1	Db3	Db5	Db7	Db10
1	729,66	30,96	69,06	69,81	71,25
2	858,91	327,73	88,79	7,77	10,66
3	1140,66	337,87	83,75	1,01	7,89
4	1592,88	235,87	48,93	15,33	12,25
5	938,35	76,01	21,22	55,68	54,60
6	1240,72	74,02	11,98	40,28	37,79
7	923,75	155,20	17,92	28,32	29,97
8	1290,94	58,15	26,90	55,62	56,91
9	178,52	415,46	109,70	7,81	22,96
10	1196,44	51,63	26,32	47,05	36,67
Avarage	1009,08	176,29	50,46	**32,87**	34,09

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C. Third case: Signal with swell

By the similarity of the sags and swell phenomena, also applies to the reference values are the length and the variation of the wave amplitude for this case PQ_Index into account both variations to estimate the impact of this phenomenon on the waveform quality.

Table 5 PQ_Index for Signal with swells using different wavelets.

Signal	ΔT	ΔU	PQ_Index				
			Db1	Db3	Db5	Db7	Db10
1	100	21,00	276,980	30,146	14,073	8,754	8,312
2	254	57,00	323,442	116,237	55,063	35,851	32,442
3	249	46,00	248,756	95,927	45,786	29,533	27,101
4	409	75,00	120,104	213,430	107,313	72,703	63,576
5	37	7,00	59,750	2,845	1,891	1,794	0,699
6	300	66,00	483,273	142,612	75,051	54,902	49,453
7	268	13,00	253,381	34,487	16,185	10,113	9,620
8	156	63,00	1049,302	48,620	23,514	15,191	14,206
9	427	11,00	88,655	46,774	21,756	13,374	12,767
10	151	75,00	1083,512	48,004	29,040	23,442	23,337

As shown in Table 6, for the case swells, again the Wavelet Db10 presenting the best results in comparison with other stem functions.

Table 6 Percentage difference for power quality indices for signal with swells

Signal	% Error_Swell				
	Db1	Db3	Db5	Db7	Db10
1	1218,95	43,55	32,98	58,31	31,05
2	467,44	103,92	3,40	37,10	43,08
3	440,77	108,54	0,47	35,80	41,09
4	60,14	184,57	43,08	3,06	15,23
5	753,56	59,36	72,99	74,37	17,20
6	632,23	116,08	13,71	16,82	25,07
7	1849,09	165,28	24,50	22,21	26,00
8	1565,56	22,82	62,68	75,89	77,45
9	705,95	325,22	97,78	21,58	16,07
10	1344,68	36,00	61,28	68,74	68,88
Avarage	903,84	116,53	41,29	41,39	36,11

IX. Power Quality Meter

Once the PQ index is determined it is proposed to be implemented the necessary software codes and hardware to allow the PQ index calculation and the developing a device to measure the distortions which present the signal.

Likewise it is also proposed to have an intelligent classifier based on *Artificial Neural Networks* (*ANN*) to identify characteristic patterns and to determine which type of phenomenon occurs. The proposed block diagram of the meter is shown in Figure 11.

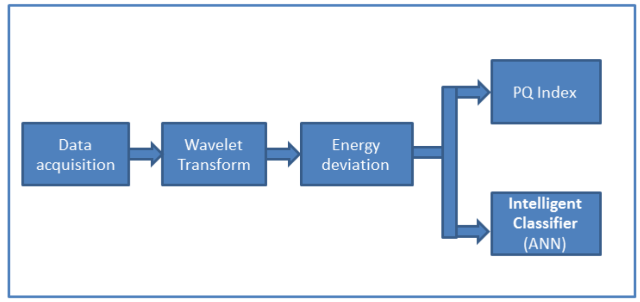

Fig. 11. Power Quality measurement and classification

X. Conclusions

In this work different phenomena that affect the power quality, later to calculate the reference values to quantify the effects they cause in the waveform simulated.

Then we proceeded to propose a general index of power quality to quantify any phenomenon and that these can be compared with each other, for this was taken into account the discrete wavelet transform since this allows to decompose the signal into different detail coefficients each with characteristics of energy.

For the calculation of the Discrete Wavelet Transform mother so that various functions used was established that is Daubechies 10 which presents better results in comparison to the index values calculated standard references.

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