Analysis of voltage and current magnification in resonant circuits on hyperspectral signal processing

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Abstract
In the recent years, electrical, electronics, and telecommunications have far-famed a rare improvement, the quantity of non-linear loads has inflated. Many electric power consumption devices are sensitive to magnetic attraction disturbances, created through nearby devices, which might have an effect on the power quality for several industry units or may be domestic users. Poor quality of power leads to fault of devices and instrumentation instability in a short period. Systematically, some research and analysis are required to monitor the disturbances of power quality which increases quality of power. This paper consists of power quality analysis on RLC circuits with voltage and current magnification values through Hyperspectral signal processing. The voltage changes and harmonic disturbances can be simulated finely with the MATLAB–Simulink simulation results and the theoretical analysis display. The simulated outcome and the Hyperspectral processing offer data and identification of power quality variances and additional control measures accurately.

Keywords
Voltage magnification, current magnification, resonance level, hyperspectral analysis, MATLAB–Simulink, RLC circuits, Power disturbance

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Introduction
In recent industry, cultivation, and day-to-day life, electric power is the leading power used. The power system is expanded with the growth of the industry. Power quality problem has come through widespread consumption of nonlinear load. The quality of power supply drops due to the PQ disturbance. The PQ disturbance also causes power coincidence. Power quality has a great effect on the safe and profitable run of the grid. Power quality reduces energy feedings guarantee of normal working in industry and scientific investigation. The PQ disturbance is detected to increase power quality.

Nonlinear loads in electrical disturbances they cause must be increasingly taken into account effect of harmonics are transformer saturation, voltage flicker, and improper operation of sensitive devices and malfunction of protective relays.

Table 1 illustrates sources and effect of harmonics. Table 2 gives some examples of products and processing in different activities.

The waveform and data of the disturbance are needed for the research on analysis and finding of disturbance. Simulink is a graphical simulation tool used.

It is a simulation tool for MATLAB. Power system and power electronics device can be simulated in Simulink. This paper constructs a power quality disturbance model based on MATLAB–Simulink, it acquires the complete simulation of voltage variation and harmonic disturbances. The evaluation of the waveform is also in the paper.

Hyperspectral data stored in a three-dimensional (3D) matrix or in an hsimage object are typically in his format, which means that the first dimension is the lines (rows) of the image, the second dimension is the samples (columns), and the third is the spectral bands. Thus, if X contains his data, \( X(1,2,3) \) is the third spectral band in the second sample in the first line.

Data in vector format are one or more (spectral) vectors in a two-dimensional (2D) matrix. Each column is a
vector, and thus the first dimension is the spectral bands and the second is the vector number. Commonly, one line of spectral data is extracted from his data and transformed to vector format in order to facilitate matrix operations. If we have a function processing one spectral vector or a line of spectral data, we do not even need to write the loop yourself. The function hsiapply applies a function to all data in a data cube and returns the result.

Hyperspectral data analysis is being used for the electrical field to accurate analysis of voltage and current magnification changes in resonant RLC circuit. Here voltage data are stored in x-axis, current data in y-axis, and time or frequency data store in z-axis versa. Figures 1, 2 and 3 show a view of Hyperspectral cube data array.

**Transitory Power Quality disturbance**

Transient and steady disturbance are the two separated parts of power quality. Voltage variation and various transient phenomena come under transient power quality problems. The voltage deviations with time, comprising voltage sag, swell, and interruption take place due to the large load transformation or system failure. The transient over voltage is meant as transient oscillation and pulse. Changes of voltage are mainly considered in this paper.

**Resonance in R-L-C circuit**

At a certain frequency, \( X_L \) becomes equal to \( X_C \). Such a condition when \( X_L = X_C \) for a certain frequency is

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**Table 1.** Sources and effects of harmonics.

| Source of harmonics | Effect |
|---------------------|--------|
| Supply side         | Demand side |
| System resonance    | Nonlinear loads (rectifiers, adjustable speed controls, fluorescent light, computers) |
|                     | 1. Electronic control malfunction |
|                     | 2. Nuisance tripping of circuit breakers |
|                     | 3. Inconsistent meter reading |
|                     | 4. Data corruption |
|                     | 5. Overheating of motors and transformers |
|                     | 6. Computer malfunctions |

**Table 2.** Some products and processing.

| Activity                        | Product                      | Processing                                             |
|---------------------------------|------------------------------|--------------------------------------------------------|
| Textile                         | Textured yarn, raw cloth, dressed socks | Drawing, heating, boiling, drying, spinning, sewing   |
|                                 | Paper, plastics, rubbers, paints, packaging material | Pressing, grinding, packing, drying mixing |
| Chemical                        | Ceramic pipes, glass shields | Cutting, grinding, machining, welding, sanding and painting |
| Mining and building material    | Tools | Milling, surface grinding, turning, drilling, cutting, pressing |
| Engineering and electrical      |                              |                                                        |

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**Figure 1.** Hyperspectral data cube.

**Figure 2.** Hyperspectral cube data array.
Table 3. Series RLC circuit.

| Supply voltage | 100 V/50 Hz | 150 V/50 Hz | 200 V/50 Hz | 230 V/50 Hz |
|----------------|-------------|-------------|-------------|-------------|
| Resistance     | 4 Ω         | 4 Ω         | 4 Ω         | 4 Ω         |
| Inductance     | 500 mH      | 500 mH      | 500 mH      | 500 mH      |
| Resonance (X_L = X_C) | 2πfrL | 2πfrL | 2πfrL | 2πfrL |
| C = 1/2πfrC    | 1/(2πfrL)   | 1/(2πfrL)   | 1/(2πfrL)   | 1/(2πfrL)   |
| I = V/Z        | 100 V/4 Ω   | 150 V/4 Ω   | 200 V/4 Ω   | 230 V/4 Ω   |
| V_L = V_C = IX_L | 25 A × 157.1 Ω | 37.5 A × 157.1 Ω | 50 A × 157.1 Ω | 57.5 A × 157.1 Ω |
| Voltage magnification | Q = 157.1 Ω/4 Ω | Q = 157.1 Ω/4 Ω | Q = 157.1 Ω/4 Ω | Q = 157.1 Ω/4 Ω |
| factor Q = 2πfrL/R | = 39.275 | = 39.275 | = 39.275 | = 39.275 |

Voltage magnification as per supply voltage.

Figure 3. A 3D hypercube with (3 rows) × (3 columns) × (3 wavelengths).

Voltage magnification factor is calculated at different levels of supply voltage, and it’s shown in Table 3. The series RLC circuit is at resonance, the magnitudes of voltages can become larger than the supply voltage and it is displayed in Figure 4.

Current magnification. By means of the parallel resonant circuit, the current taken from the supply can be magnified. This type of resonance is called current resonance. Quality factor of R-L-C parallel circuit is the current magnification in the circuit at resonance.

Current magnification = Circulating current in X_L / Current (I) from the mains (or) I_c / I

\[
I_c = I_L \sin \phi_L \\
I = I_L \cos \phi_L \\
Q = \frac{I_L \sin \phi_L}{I_L \cos \phi_L} = \frac{\omega_L}{R}
\]  

where Q is a measurement of current magnification, current at resonance = I = V / Z_0, Z_0 = L / R_C, I = V / (L / (R_C)) = VR_C / L.

As shown in Table 4, when the parallel R-L-C circuit is at resonance, the magnitudes of the current become increasingly based on given supply voltage and it is shown in Figure 5.

\[
Q = \frac{1}{R} \sqrt{\frac{L}{C}}
\]
Power quality disturbances

Power quality disturbances are divided into

(i) Steady state deviations—Small variations from the desired current or voltage values

1. Voltage fluctuations
2. Current and Voltage destabilize
3. High-frequency noise
4. Harmonic distortion

(ii) Events—Unexpected deviations of current or voltage from the nominal wave shape

1. Interruptions
2. Voltage Sag and Swell
3. Transients
4. Earthing problems

Sensitive power quality disturbances

The power quality disturbances sensitively affects the following fields:

1. Computer networking
2. Telecommunication
3. Electronics manufacturing
4. Bio-technology and pharmaceutical lab
5. Commercial data-processing

Current and voltage measurement in series R-L-C circuits

The power quality monitoring is essential due to increased necessities of control in power systems for utilities. Simulation models are designed to measure the dissimilarity of current and voltage levels in the circuit. Monitoring power quality is done by measurements of voltage events in a certain frequency range to identify changes in series RLC circuits. RLC circuit is simulated using MATLAB-Simulink to find transient deviations in particular frequency levels and examined using hyperspectral data analysis.

The necessity for power disturbance analysis

The necessity for power disturbance analysis is due to the following reasons:

1. Ensures power system reliability
2. Detects the source and frequency of events
3. Preventive and predictive maintenance
4. Assessment of incoming electrical supply and distribution to determine if power quality instabilities are impacting
5. Decide the need for mitigation equipments
6. Power disturbance monitoring systems permits to spot the most sensitive equipment’s and install power conditioning systems wherever needed
7. Saving of energy expenses and risk anticipations.

Existing methods of power quality analysis

The existing methodology of power quality analysis utilized in monitoring systems are as follows:

(i) Discrete Fourier transform

| Table 4. Parallel RLC circuit. |
|--------------------------------|
| Supply voltage | 100 V / 50 Hz | 150 V / 50 Hz | 200 V / 50 Hz | 230 V / 50 Hz |
|----------------|----------------|----------------|----------------|----------------|
| Resistance R   | 60 Ω           | 60 Ω           | 60 Ω           | 60 Ω           |
| Inductance L   | 200 mH         | 200 mH         | 200 mH         | 200 mH         |
| Capacitance C  | 120 μF         | 120 μF         | 120 μF         | 120 μF         |
| Resonant frequency \( f_r \) | \( 1/(2\pi \sqrt{0.2 \cdot 120 \cdot 10^{-2}}) \) | \( 1/(2\pi \sqrt{0.2 \cdot 120 \cdot 10^{-2}}) \) | \( 1/(2\pi \sqrt{0.2 \cdot 120 \cdot 10^{-2}}) \) | \( 1/(2\pi \sqrt{0.2 \cdot 120 \cdot 10^{-2}}) \) |
| Current magnification \( I_{mag} \) | \( Q \times I = 1.47 \times 1.67 \) | \( Q \times I = 1.47 \times 2.5 \) | \( Q \times I = 1.47 \times 3.33 \) | \( Q \times I = 1.47 \times 3.83 = 5.63 \) A |
| Current magnification factor \( Q = R / \omega L \) | \( 60 \Omega / 40.8 \Omega \times 1.47 = 2.45 \) A | \( 60 \Omega / 40.8 \Omega \times 1.47 = 3.67 \) A | \( 60 \Omega / 40.8 \Omega \times 1.47 = 4.89 \) A | \( 60 \Omega / 40.8 \Omega \times 1.47 = 6.03 \) A |

Figure 5. Current Magnification as per supply voltage.

The power quality disturbances sensitively affects the following fields:

1. Computer networking
2. Telecommunication
3. Electronics manufacturing
4. Bio-technology and pharmaceutical lab
5. Commercial data-processing
It is an efficient algorithm available to analyze discrete periodic signals. For a signal $x[n]$ with fixed length $N$, the DST is outlined in line with ensuing relation

$$X(k) = \sum_{n=0}^{N-1} x[n] e^{-j\frac{2\pi nk}{N}}$$

where $k = 0, 1, ..., N-1$.

Figure 6 shows sinusoidal signal disturbed with harmonic distortions.

In Figure 7 is taken into account a curved signal disturbed by impulsive transient.

(ii) Short-time Fourier Transform

It is another efficient algorithm that deals with information in the time and frequency domain concerning disturbances. Typically, signal parameters (amplitude, frequency, and phase) do not seem to be constant in time

$$X[n1,\lambda] = \sum_{m1=0}^{\infty} x[n1 + m1] \omega[m1] e^{-j\lambda m1}$$

Power quality disturbances cover a frequency spectrum, ranging from a number of Hertz to a number of limited Mega Hertz. A sinusoidal signal (50 cycles per second) is disturbed by an oscillatory transient (1000 cycles per second). The spectrograms for rectangular, the STFT of an oscillatory transient18 are displayed in Figure 8.

(iii) Discrete wavelet transform

Multi-resolution signal decomposition relies on subbands segregation using low-pass and high-pass filtering. A wavelet may be a waveform of restricted period, sometimes irregular and uneven.19 For a discrete signal $x[n]$, the discrete transform is outlined

$$x(t) = A_{j0}(t) + \sum_{j=0}^{j0} D_j(t)$$

The wavelet transform level is shown in Figure 9.

(iv) Discrete Stockwell transform

The $S$-transform is a simplification of the short-time Fourier transform, extending the continuous wavelet transform. The $S$-transform of the $N$ point time series $h[kT]$ is

$$S[T, \frac{n1}{NT}] = \sum_{m=0}^{N-1} H \left( \frac{m1 + n1}{NT} \right) e^{-\frac{2\pi im1}{m1} - \frac{2\pi in1}{n1}}$$

where $n0$ and $H[n1 / NT]$ is the time series in Fourier Transform.

Figure 10 shows the 3D ST plots for each signals used to determine the amplitude deviations of the frequency spectral elements within the signals.
Design of voltage variation model

Short faults occur rottenly. Single phase earthing fault is the most fault of distribution and transmission system, which is the leading cause of voltage sag.\(^2\) The power system voltage fluctuation, interruption, current swell, swells, and voltage swag are the faults created by single phase earthing fault. The different types of power disturbance inputs like normal condition, constant input value, sag, swell condition, interference condition and pulse generation using switch condition are checked in RLC circuits shown in Figure 11(a)–(e).

Hyperspectral data

RLC circuits are simulated in MATLAB–Simulink application and output data are collected through workspace scope tools and signals are viewed in scope signal analyzer tool.\(^2\) The different types of power disturbance checked in RLC circuit and respective values are clearly viewed. In this analysis, voltage and current values are separately collected and viewed in scope analyzer tool. The voltage and current values are analyzed in 10 s time/frequency range.

The collected works space values are stored and viewed in hyperspectral cube\(^2\) as shown in Figure 12(b). Here x-axis represents voltage, y-axis represents current, and z-axis represents time/frequency value.

Table 5 shows voltage and current values collected from RLC circuits in normal input condition and its respective waveform shown in Figure 12(a). Figure 12(b) shows hyperspectral 3D cube (spatial and spectral view) which is generated by MATLAB code, and it is used to represent data as x $\rightarrow$ voltage, y $\rightarrow$ current, and z $\rightarrow$ time/frequency.

Methodology

Voltage magnification analysis for RLC circuits using hyperspectral processing have been implemented through MATLAB–Simulink application and collected voltage and current values are viewed in MATLAB–Simulink mesh-grid and surf view. This type of viewing helps to analyze the magnification levels of different types of power disturbance condition.\(^2\)\(^3\)\(^4\) The detail steps of Voltage magnification analysis are as follows.

Step 1. Normal 230 V and 50 Hz inputs are tested in RLC simulation circuit.
Step 2. Voltage and current values are collected through the MATLAB–Simulink workspace tool.
Step 3. Workspace values are viewed in Excel and voltage, current, and time/frequency values are stored in hyperspectral data cube.

Step 4. Hyperspectral data cube values are separated in x-axis, y-axis, and z-axis as voltage, current, and time/frequency values, respectively.

Step 5. The separated values are visualized in MATLAB–Simulink trimesh and surf views.

Step 6. MATLAB trimesh and surf views shows clearly the voltage magnification levels at different types of power disturbance condition.

Discussion

The different voltage disturbance to the power system caused by the fault location parameters and the different fault types are shown in the analysis. The two-phase shorting causes the scale of voltage drop and rise, it is also different from them. Even in the different fault position, the similar kind of shorting fault causes sag and swell of voltage.25

Table 6 shows the summary of IEEE Std 1159-1995 power quality categories. The short time voltage changes are common power quality distribution in the power system, it is shown in Figure 7. And the voltage changes can be simulated well. The Hyperspectral 3D data cube26 is used to analyze spatial and spectral information comparing with different time/frequency level of data and find the period of power disturbance with its respective magnification values. This model can support to realize all voltage deviations and the identification of the voltage change disturbance.27,28

Experimental results

In this section, the voltage and current values are simulated in MATLAB–Simulink application in normal condition and abnormal power disturbance conditions. The same data are viewed and analyzed in Signal analyzer and 3D mesh-grid and surf views.29,30 Figures 13–15 show the waveform using constant value (1,2,0.5) as an input condition and Figure 16 shows the waveform generated using sag/swell as an input condition. Table 7 shows the voltage and current values of RLC circuit by interference input condition which is generated using MATLAB–Simulink. Current and voltage values at interference condition upto 0.001s time/frequency range are shown in Figure 17(a) and (b).

Table 8 shows maximum magnitude value of voltage and current in particular time/frequency at sag/swell and interference conditions.10

Figure 18 shows Voltage and Current waveform alongside power after the Interference power variation. Figure 19 shows the various RLC circuit input condition and signal output viewed in MATLAB–Simulink scope viewer. Also Figure 20 shows the MATLAB–Simulink surf view of hyperspectral cube voltage, current, and time/frequency values of RLC series circuit.
workspace depicted in x-, y-, and z-axis, respectively. Figure 21 shows maximum voltage and current magnification values of some specific time/frequency range. The above results are clearly analyzed by voltage and current magnification data at particular time/frequency range using with hyperspectral signal processing methods.

Table 6. Summary of IEEE standard power quality categories.

| Category                  | Types                        | Typical duration | Common causes                                           |
|---------------------------|------------------------------|------------------|---------------------------------------------------------|
| Transients                | Impulsive, oscillatory       | Less than 1 cycle| Lightning switching loads                               |
| Short duration variations | Sags, swells, interruptions  | Less than 1 min  | Faults, motor starting utility protective equipment      |
| Long durations variations | Sustained interruptions, under voltages, over voltages | Over 1 min | Poor voltage regulation, incorrect transformer tap setting, overloaded feeder, utility equipment |
| Voltage imbalance         | –                            |                  | Steady state                                            |
| Waveform distortion       | Harmonics, notching, noise   |                  | Steady state                                            |
| Voltage fluctuations      | Flicker                      |                  | Intermittent                                            |
| Power frequency variations| –                            | Less than 10 s    | Poor generator control                                  |

Figure 13. Voltage and current waveform nearby power after the constant value 1 as an input condition.

Figure 14. Voltage and current waveform close to power after the constant value 2 as an input condition.

Figure 15. Voltage and current waveform next to power after the constant value 0.5 as an input condition.

Table 7. Voltage and current values of RLC interference input value.

| Current Time/frequency Data | Voltage Time/frequency Data |
|-----------------------------|------------------------------|
| 0.0001 0.084092 0.0001 8.409214 |
| 0.0002 0.168101 0.0002 16.81013  |
| 0.0003 0.251945 0.0003 25.19445  |
| 0.0004 0.335539 0.0004 33.55392  |
| 0.0005 0.418803 0.0005 41.88026  |
| 0.0006 0.501653 0.0006 50.16528  |
| 0.0007 0.584008 0.0007 58.40079  |
| 0.0008 0.665787 0.0008 66.57867  |
| 0.0009 0.746908 0.0009 74.69084  |
| 0.001 0.827293 0.001 82.72929  |
| 0.0011 0.906861 0.0011 90.68611  |
| 0.0012 0.985534 0.0012 98.55343  |
| 0.0013 1.063235 0.0013 106.3235  |
| 0.0014 1.139886 0.0014 113.9886  |
| 0.0015 1.215413 0.0015 121.5413  |
| 0.0016 1.289739 0.0016 128.9739  |
| 0.0017 1.362794 0.0017 136.2794  |
| 0.0018 1.435403 0.0018 143.5403  |
| 0.0019 1.504796 0.0019 150.4796  |
| 0.002 1.573605 0.002 157.3605  |

Figure 16. Voltage and current waveform beside power after the sag/swell power variation value as an input.
Conclusion

The fundamental target is extraction of power quality instabilities so as to realize disturbance recognition. The simulation model built in MATLAB-Simulink platform presented in this paper is relevant to analyze the affected magnification levels and harmonic disturbance of voltage and current changes. The wavelets of voltage swell, sag, and interference are obtained from the recreation model. The paper in addition examines the current and voltage contained harmonic using hyperspectral data cube analyzing methods. The paper contains a detailed discussion on power quality analysis on RLC circuits with voltage and current values through hyperspectral signal processing. Hyperspectral data cube analyzing exploits accurate details of voltage and current magnification levels in different time/frequency levels. The simulation outcomes and the theoretical analysis give us accurate information of transient power changes in the power system. And also it helps to troubleshoot the problem, reduce the losses, and maintain the constant power quality.

Table 8. Maximum magnitude value of particular frequency.

| Time/frequency | Sag/swell condition | Interference condition |
|----------------|---------------------|------------------------|
|                | Current             | Voltage                | Current             | Voltage                |
| 0.005          | 3.786099            | 378.6099               | 2.677176            | 267.7176               |
| 0.0049         | 3.784231            | 378.4231               | 2.675855            | 267.5855               |
| 0.0051         | 3.784231            | 378.4231               | 2.675855            | 267.5855               |
| 0.0048         | 3.778628            | 377.8628               | 2.671893            | 267.1893               |
| 0.0052         | 3.778628            | 377.8628               | 2.671893            | 267.1893               |
| 0.0047         | 3.769296            | 376.9296               | 2.665295            | 266.5295               |
| 0.0046         | 3.756244            | 375.6244               | 2.656066            | 265.6066               |
| 0.0045         | 3.739486            | 373.9486               | 2.644216            | 264.4216               |
| 0.0044         | 3.719037            | 371.9037               | 2.629756            | 262.9756               |
| 0.0043         | 3.694917            | 369.4917               | 2.612701            | 261.2701               |
| 0.0042         | 3.667152            | 366.7152               | 2.593068            | 259.3068               |
| 0.0041         | 3.635767            | 363.5767               | 2.570875            | 257.0875               |
| 0.004          | 3.600794            | 360.0794               | 2.546146            | 254.6146               |

Figure 17. (a) Current value at interference condition up to 0.001 s time/frequency range and (b) voltage value at interference condition up to 0.001 s time/frequency range.

Figure 18. Voltage and current waveform alongside power after the interference power variation.
Figure 19. (a)–(d) Voltage and current waveform beside power after the input pulse generation using switch (constant value (0.5, 1), (1.1.5), (1.5, 2), (2.3), (0, 0.5)).
Figure 20. Continued.
Figure 20. (a) Voltage and current values of RLC normal input condition viewed in MATLAB–Simulink hyperspectral data 3D surf view, (b) voltage and current values of RLC normal input condition viewed in MATLAB–Simulink trimesh hyperspectral data 3D trimesh view, (c) voltage and current values of RLC sag/swell input condition viewed in MATLAB–Simulink hyperspectral data 3D surf view, (d) voltage and current values of RLC interference input condition viewed in MATLAB–Simulink hyperspectral data 3D surf view, (e) voltage and current values of RLC pulse generation using switch input condition viewed in MATLAB–Simulink hyperspectral data 3D surf view, (f) voltage and current values of RLC pulse generation (0.5, 1) using switch input condition viewed in MATLAB–Simulink hyperspectral data surf view, (g) voltage and current values of RLC pulse generation (1, 1.5) using switch input condition viewed in MATLAB–Simulink hyperspectral data surf view, (h) voltage and current values of RLC pulse generation (1.5, 2) using switch input condition viewed in MATLAB–Simulink hyperspectral data surf view, (i) voltage and current values of RLC pulse generation (2, 3) using switch input condition viewed in MATLAB–Simulink hyperspectral data surf view, (j) voltage and current values of RLC pulse generation using switch input condition viewed in MATLAB–Simulink hyperspectral data 3D Waterfall view, (k) voltage and current values of RLC pulse generation using switch input condition viewed in MATLAB–Simulink hyperspectral data 3D mesh view, and (m) maximum magnitude value of voltage and current in particular time/frequency viewed in MATLAB–Simulink hyperspectral data surf view.
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Figure 21. (a) Maximum current magnitude value and (b) maximum voltage magnitude value.
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