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G1U UR2320 UR3100

(56) Documents Cited
GB 2281629 A
US 5365164 A
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US 4031462 A

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(54) Abstract Title
Measuring harmonic emissions from electrical apparatus

(57) Harmonic emissions from electrical apparatus are sensed to produce a signal f(t) representing the emissions. This signal is processed to produce real and imaginary components of the emissions. This processing may take the form of a correlation technique for each harmonic k. The signal f(t) is multiplied by a sine or cosine wave of a frequency appropriate to the harmonic and then the product from each multiplication is integrated to produce real and imaginary components. From these, the level of the harmonic may be calculated and compared against a standard. The results of the processing may be displayed on an Argand diagram, and the resolution achieved may be 20ms with a 50Hz mains supply.

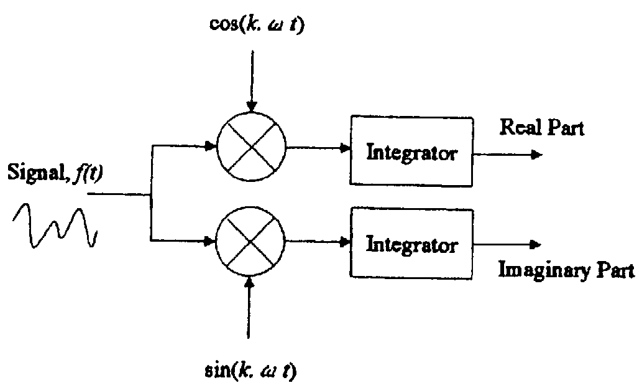

FIGURE 1

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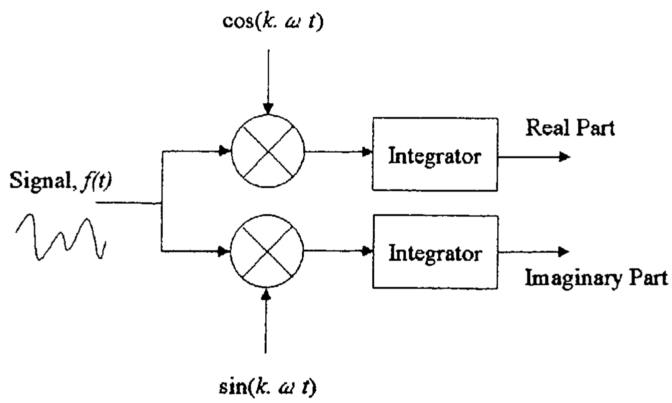

FIGURE 1

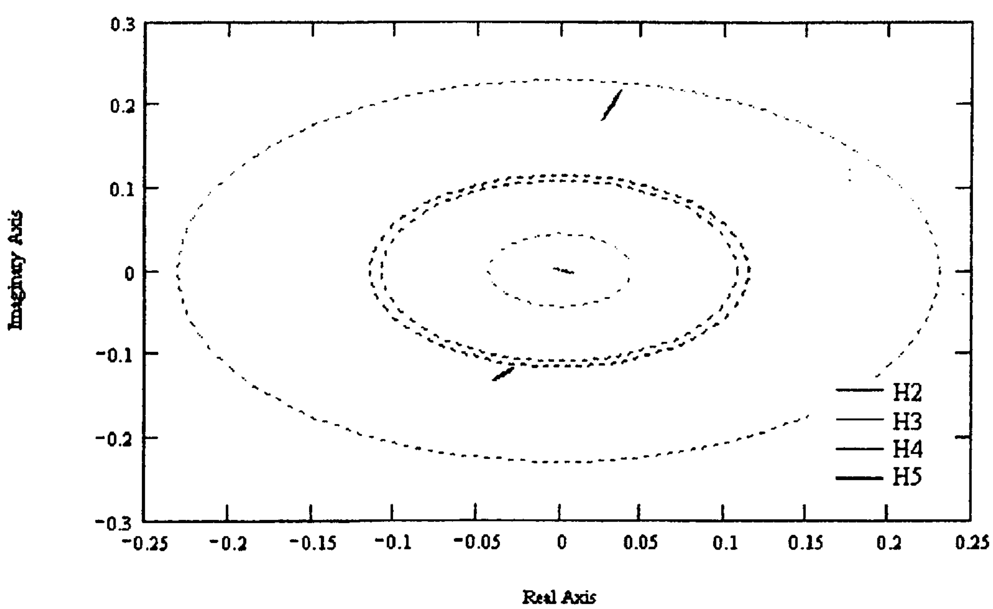

FIGURE 2

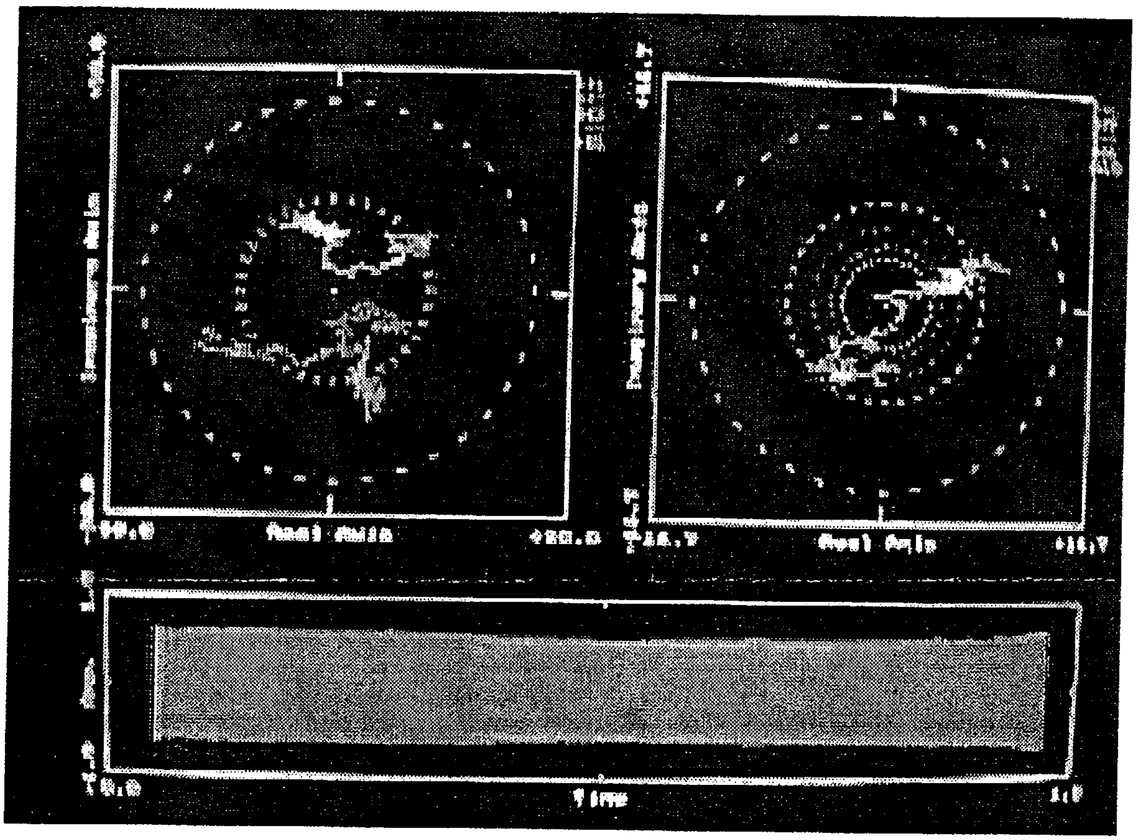

FIGURE 3

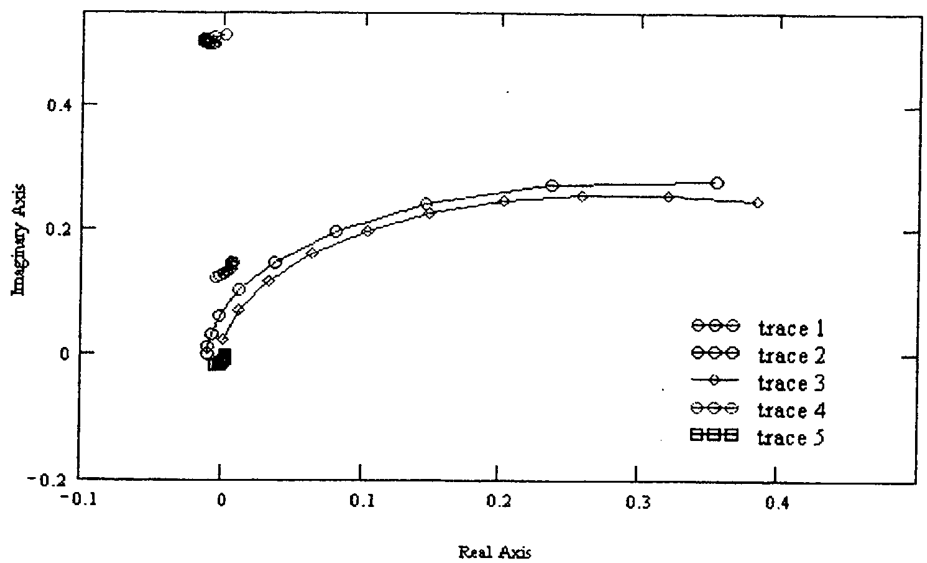

FIGURE 4

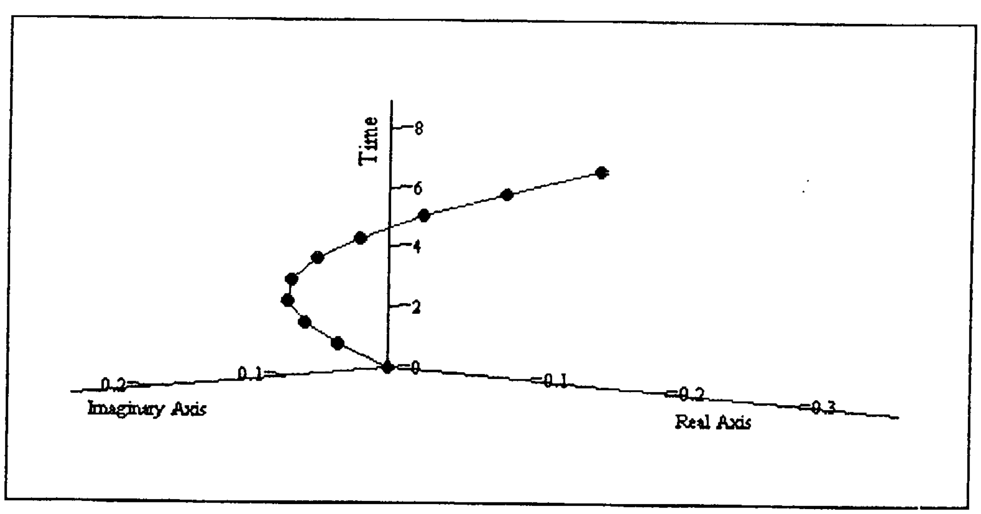

FIGURE 5

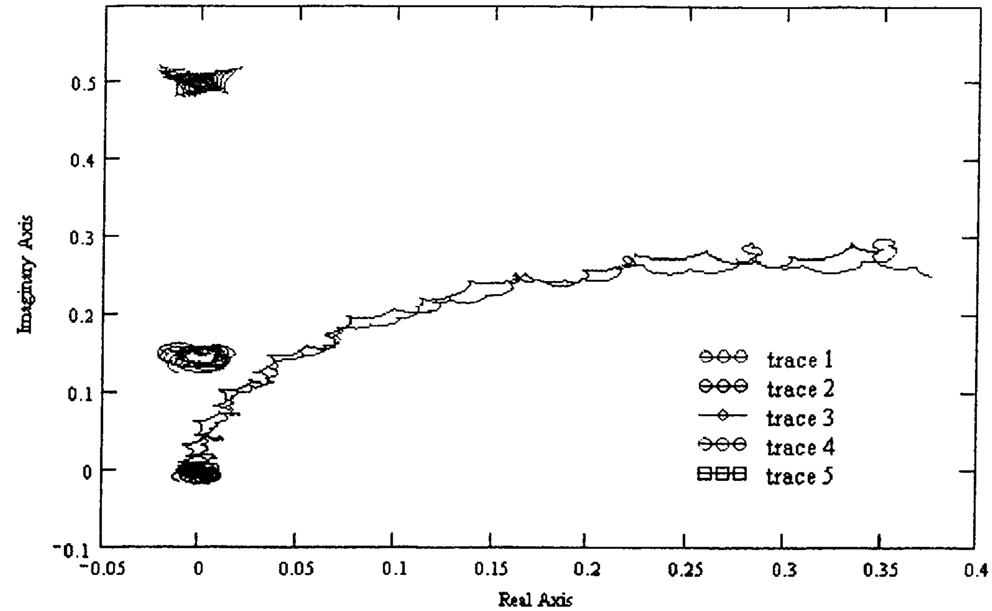

FIGURE 6

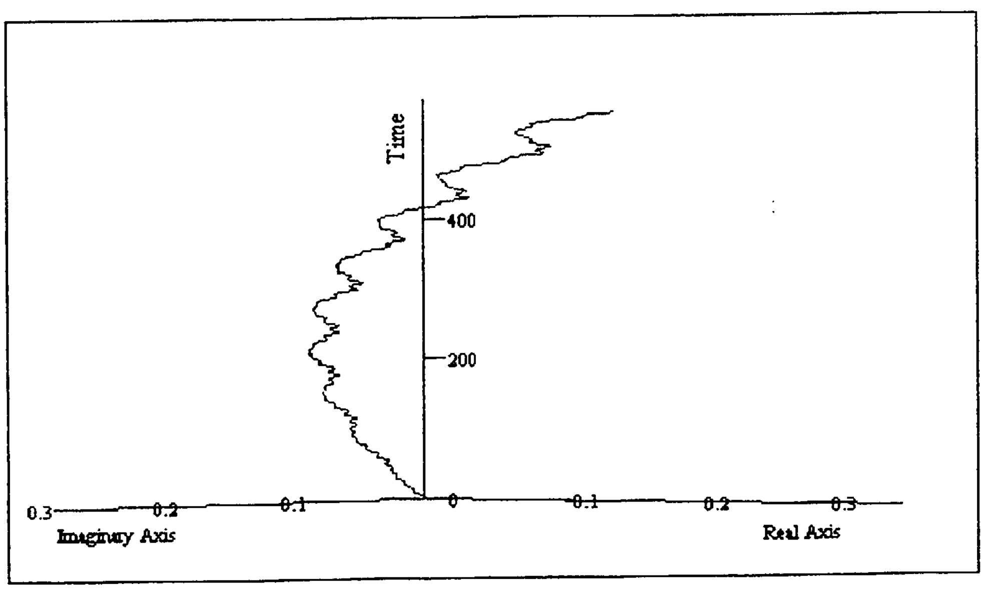

FIGURE 7

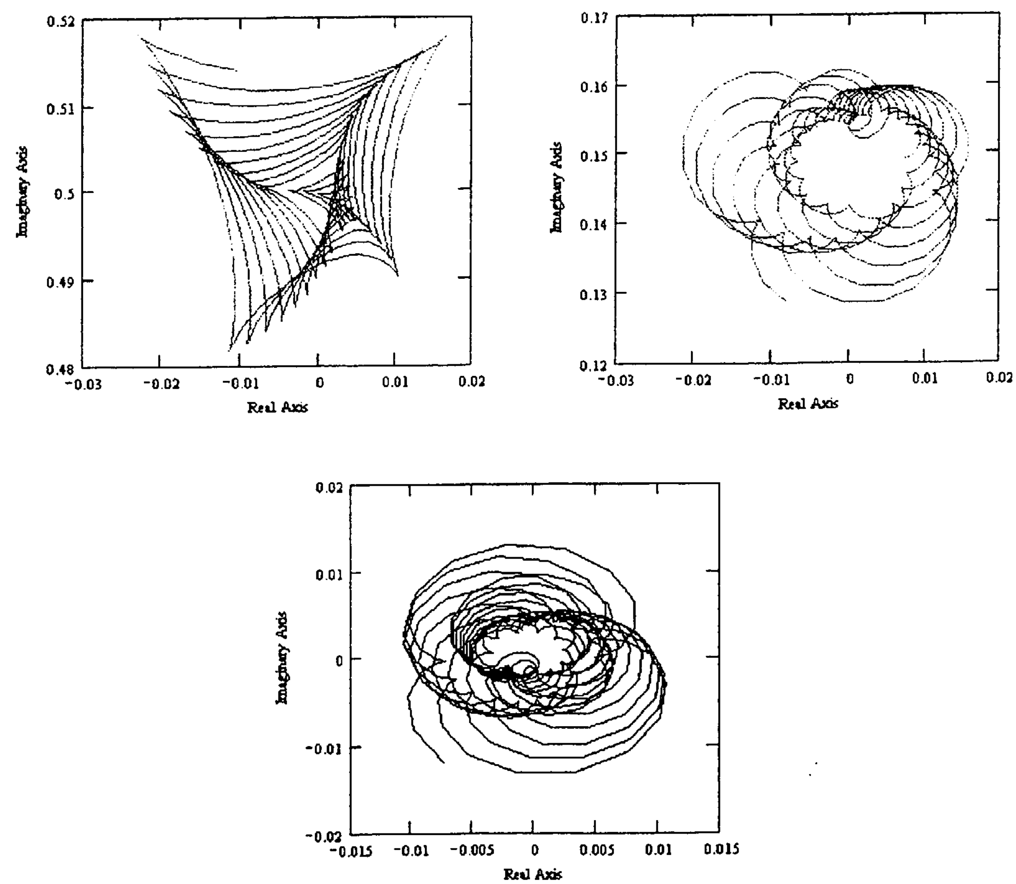
0.52
0.51
0.5
0.49
0.48
-0.03
-0.02
-0.01
0
0.01
0.02
Real Axis
Imaginary Axis
0.17
0.16
0.15
0.14
0.13
0.12
-0.03
-0.02
-0.01
0
0.01
0.02
Real Axis
Imaginary Axis
0.02
0.01
0
-0.01
-0.02
-0.015
-0.01
-0.005
0
0.005
0.01
0.015
Real Axis
Imaginary Axis

FIGURE 8

TESTING OF ELECTRICAL APPARATUS

The present invention relates to the testing of electrical apparatus, in particular to the measuring of harmonic emissions from electrical apparatus.

It is a well known fact that electrical apparatus coupled to a harmonic power source, such as the mains electricity supply, produces harmonic emissions. There is also in place a regulatory standard (EN61000-3-2), which prescribes limits on the amplitude of harmonics drawn by electrical appliances connected to the electricity mains supply.

However, the known testing systems generally have a resolution which can miss harmonic emission spikes, such as may be emitted in the course of a change in operation of the appliance. For example, a standard system has a measurement resolution of around 320 ms (16 cycles), which can be longer than the duration of a transition spike. Moreover, the known testing systems can produce results which are relatively difficult to interpret, particularly during periods of changing emissions from an appliance.

The present invention seeks to provide improved measuring of harmonic emissions from electrical apparatus.

According to an aspect of the present invention, there is provided a method of measuring harmonic emissions from electrical apparatus including the steps of sensing emissions from said apparatus and generating an input signal therefrom, processing the input signal to obtain real an imaginary components of the sensed emissions, and determining from the real and imaginary components the level of the sensed harmonic emissions.

Advantageously, the input signal is digitised prior to processing.

Preferably, the fundamental frequency of the input signal is determined by phase locking the input signal on digitisation to the fundamental frequency.

For each harmonic of interest, the real and imaginary parts of the signal are advantageously determined by finding the correlation of the signal with the cosine and sine of each harmonic frequency at each of a plurality of points in time. In the case of the real part, this is preferably by multiplication of the signal and a synthesised cosine signal at the given harmonic frequency. For the imaginary part, this process is preferably carried out with by multiplication with a synthesised sine signal.

In the preferred embodiment, the output of the two paths (cosine and sine) is integrated. Typically, an integer number of fundamental cycles is used. The integration can stepped or sliding.

In the preferred embodiment, the real and imaginary components are displayed in graphical form, preferably as an Argand diagram.

According to another aspect of the present invention, there is provided a system for measuring harmonic emissions from electrical apparatus including sensing means for sensing emissions from apparatus and for generating an input signal therefrom, processing means for processing the input signal to obtain real an imaginary components of sensed emissions and for determining from the real and imaginary components the level of the sensed harmonic emissions.

Advantageously, the system includes an analogue to digital converter for digitising the input signal prior to processing.

Preferably, there is provided a phase locked loop for determining the fundamental frequency of the input signal by phase locking the input signal on digitisation to the fundamental frequency.

The processing means is preferably operable to determine the real and imaginary parts of the signal, advantageously by finding the correlation of the signal with the cosine and sine of each harmonic frequency at each of a plurality of points in time. In the case of the real part, this is preferably by multiplication of the signal and a synthesised cosine signal at the given harmonic frequency. For the imaginary part, this process is preferably carried out with by multiplication with a synthesised sine signal.

In the preferred embodiment, there is provided integrating means for integrating the output of the two paths (cosine and sine). Typically, an integer number of fundamental cycles is used. The integration can stepped or sliding.

Advantageously, the system includes display means operable to display the results of a measurement in graphical form. The display means is preferably operable to generate an Argand diagram.

An embodiment of the present invention is described below, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of the preferred embodiment of measuring system;

Figure 2 is an Argand diagram being one embodiment of graphical representation of the measurement results, showing harmonic trajectories and limit circles;

Figure 3 is a screen photograph depicting the operation of the measurement system;

Figure 4 is an Argand diagram for cycle-by-cycle integration;

Figure 5 is a trajectory plot for a third harmonic of a measured emission;

Figure 6 is an Argand diagram for sliding window integration;

Figure 7 is a trajectory plot for a third harmonic (sliding window integration); and

Figure 8 shows various graphs of harmonics 1, 4 and 5 (sliding window integration).

The embodiment of system and method described makes use of computational algorithms which produce a measurement result which can be displayed in graphical form to assess the trajectory of the harmonics in a fluctuating (non-stationary) signal such that the harmonics can be assessed against maximum limits. The algorithms themselves provide higher resolution than prior art algorithms, 20 ms with 50 Hz mains electricity supply (that is, one cycle resolution). Thus, real time changes can be detected, as explained below. The preferred embodiment produces an Argand diagram to display the results, although other forms of display could be used.

Referring to Figure 1, the signal to be analysed (the signal) is digitised using an analogue to digital converter (ADC).

The fundamental frequency of the signal is made available to the algorithm by phase locking the samples taken by the ADC to the fundamental frequency, by means of a phase locked loop (not shown).

For each harmonic of interest, the real and imaginary parts of the signal are determined by finding the correlation of the signal with the cosine and sine of each harmonic frequency at each point in time. In the case of the real part, this is by multiplication of the signal and a synthesised cosine signal at the given harmonic frequency. For the imaginary part, this process is carried out by multiplication with a synthesised sine signal.

The output of the two paths (cosine and sine) is then integrated. In general, an integer number of fundamental cycles is used. The integration can stepped or sliding.

The process is shown schematically in Figure 1, where $f(t)$ is a digitised version of the signal. Each path produces a single value after each integration period, these being representative of the real and imaginary parts of a given harmonic. These can be plotted on a real and imaginary axis (an Argand) diagram as shown in Figure 2.

For a given fluctuating harmonic, the points will, in general, plot the trajectory of the harmonic with time (a third time axis can be added if necessary, to provide time information).

It will be apparent that this system has similarities to a Fourier Transform. However, as it uses a non-stationary (non-repetitive) signal it is modified, as the infinite time integral has no resolution in time. In this embodiment, an integer number of cycles is used in the integration, which effectively breaks up the transform into blocks.

Regulatory standards prescribe limits on harmonics in terms of the magnitude of each harmonic. Magnitudes are represented in this embodiment on an Argand diagram by circles (Figure 2). For each harmonic limit, circles are plotted on the diagram at a value corresponding to the magnitude limit. The analysis of the signal gives rise to a trajectory for a given fluctuating harmonic which must remain within the circle in order to pass the regulatory condition.

Figure 3 shows a screen view of an implementation of the algorithm. The screen (display) gives two Argand diagrams in the top two thirds of the screen, the left hand display for the low number harmonics and the right hand side for the higher harmonics. Circles are also superimposed on the displays, which give the harmonic limits desired or required for the particular type of apparatus under test. The bottom part of the screen shows the signal data as it is sampled.

In some cases, regulations allow the limit to be exceeded for a certain period of time. In the case of this embodiment, this translates to the proportion of points outside the circle.

In terms of graphical presentation, colours can be used to represent different harmonics.

Detailed Explanation

There follows a detailed explanation of the computational algorithms used in the preferred embodiment.

Consider a signal *f(t)*, its Fourier Transform at the k^{th} harmonic is given by the correlation of the signal with a complex exponential at a required harmonic frequency $k.\omega$.

$$F(k.\omega) = \int_{-\infty}^{\infty} f(t).e^{j.k.\omega t}\,dt \quad \cdots \quad (1)$$

This can also be written in terms of the real and imaginary parts,

$$\Re(F(k.\omega) = \int f(t).\cos(k.\omega.t)dt \quad \cdots \quad (2)$$
$$\Im(F(k.\omega) = \int f(t).\sin(k.\omega.t)dt \quad \cdots \quad (3)$$

The analysis can be represented by processing components as shown Figure 1.

If *f(t)* is a stationary signal, the limits of the integration in equations 2 and 3 can be reduced to the repeat period of the stationary signal and the equations will yield single values for each frequency $k.\omega$. If these real and imaginary parts are plotted on an Argand diagram, a single point results for each frequency.

Consider the case where *f(t)* is a smooth non-stationary waveform, where each harmonic is varying in amplitude and phase, such that,

$$\begin{aligned} f(t) &= h_1(t).\cos(\omega.t) + h_2(t).\cos(2.\omega.t) + \ldots h_N(t).\cos(N.\omega.t) \\ &\quad + j_1(t).\sin(\omega.t) + j_2(t).\sin(2.\omega.t) + \ldots j_N(t).\sin(N.\omega.t) \quad \cdots (4) \end{aligned}$$

where, in general, the modulating functions $h_n(t)$ and $g_n(t)$ are arbitrary functions of time.

As the signal is non-stationary it is not possible to reduce the integral limits to finite limits and in general it is necessary to window the signal in some manner such that equations 2 and 3 may be evaluated. In general, the result of this windowed integration no longer yield single points on the Argand diagram, but gives rise to time varying loci.

Simulations

The following test signal f_n was simulated:

$$f_n := \sin(\omega \cdot 1 \cdot n) + \left(\frac{n}{NC}\right)^2 \cdot \sin\left[(\omega \cdot 2 \cdot n) + \frac{n}{NC}\right] + \frac{n}{NC} \cdot \sin\left[(\omega \cdot 3 \cdot n) + \frac{n}{NC}\right] + 0.3 \cdot \sin((\omega \cdot 4 \cdot n))$$

The total number of samples NC was 640. Ten cycles were simulated with 64 samples per cycle. In this example both the first and forth harmonic are stationary, while the second and third harmonic are modulated in amplitude and phase by functions of time (sample number n).

The real and imaginary part as given in equations 2 and 3 were by calculated numerical integration (summation). It was necessary to window the signal in order to calculate the integral with finite limits. Two schemes were used for this:

(i) using a window equal to the fundamental period and integrating on a cycle by cycle basis. In this example which has ten cycles, this produces ten results;

(ii) using a window equal to the fundamental period and integrating. The window is then slid by one sample and the integration repeated. The sliding/integration is repeated to cover the entire signal sequence, producing many results.

As with Short Time Fourier Transforms, a choice of window size as well as smoothing function (hanning etc.) is possible at this stage.

The integrals in equations 2 and 3 were evaluated for the first through to the fifth harmonic ($k = 1..5$). The resulting real and imaginary parts were then plotted on an Argand diagram.

Figure 4 shows the results using cycle by cycle integration, where the trace numbers correspond to the harmonic numbers. It can be seen from Figure 4 that components which are not modulated produce relatively little deviation on the plot with all the points clustered together. Harmonics which are modulated produce a sweep on the plot, as can be seen for the second and third harmonics.

It is expected that non-modulated signals should produce a single point on the Argand diagram. In this example, a small deviation from a single point is seen for the non-modulated harmonics. This effect is due to cross coupling with the modulated harmonics. Furthermore, note there was no 5^{th} harmonic component in the signal, instead of a single point at zero, as may be expected, the result is a cluster of points around the origin.

The modulated harmonics sweep across the diagram effectively showing the trajectory of these components as their amplitude and phase changes in time. This leads to the possibility of the introduction of a time axis to the plots as shown in Figure 5.

Figure 6 shows the results when sliding window integration is used. The results show similar characteristics to Figure 4. A trajectory plot is shown in Figure 7. Close up detail of harmonics 1,4 and 5, are shown in Figure 8. Again, these are not single points due to the cross coupling of the modulated components.

Application to Harmonic Measurement/Limits

A harmonic of zero amplitude will produce a point (or cluster of points) at the origin. As the strength of the harmonic increases, the points on the diagram become further from the origin. Limits in the magnitude of a given harmonic would then be represented by a circle centred on the origin, whose radius is determined by the allowed limit. To allow for fluctuating harmonics, it may pragmatic for a certain percentage of points to stray outside the limiting circle (but perhaps be limited by a less stringent larger circle).

Any electrical device can be tested by this system. An example might be a washing machine. During changes in the operation of the machine, for example during the intake of water or at the start of a spin cycle, the emissions from the machine will normally change as a result of changes in the amount of current drawn by the machine. The test system described above is particularly suited to detecting these changes in emissions because of the much better resolution compared to prior art measurement systems. The display of the results in graphical form allows easy monitoring of the emissions and a clear indication of the occurrence of emissions above the desired level.

CLAIMS

1. A method of measuring harmonic emissions from electrical apparatus including the steps of sensing emissions from said apparatus and generating an input signal therefrom, processing the input signal to obtain real an imaginary components of the sensed emissions, and determining from the real and imaginary components the level of the sensed harmonic emissions.

2. A method according to claim 1, wherein the input signal is digitised prior to processing.

3. A method according to claim 1 or 2, wherein the fundamental frequency of the input signal is determined by phase locking the input signal on digitisation to the fundamental frequency.

4. A method according to any preceding claim, wherein for each harmonic of interest, the real and imaginary parts of the signal are advantageously determined by finding the correlation of the signal with the cosine and sine of each harmonic frequency at each of a plurality of points in time.

5. A method according to claim 4, wherein in the case of the real part, the correlation is found by multiplication of the signal and a synthesised cosine signal at the given harmonic frequency.

6. A method according to claim 4 or 5, wherein for the imaginary part, the correlation is carried out with by multiplication with a synthesised sine signal.

7. A method according to any preceding claim, wherein the output of the two paths is integrated.

8. A method according to claim 7, wherein an integer number of fundamental cycles is used.

9. A method according to claim 7 or 8, wherein the integration is stepped or sliding.

10. A method according to any preceding claim, wherein the real and imaginary components are displayed in graphical form

11. A method according to claim 10 , wherein the graphical form is an Argand diagram.

12. A system for measuring harmonic emissions from electrical apparatus including sensing means for sensing emissions from apparatus and for generating an input signal therefrom, processing means for processing the input signal to obtain real an imaginary components of sensed emissions and for determining from the real and imaginary components the level of the sensed harmonic emissions.

13. A system according to claim 12, including an analogue to digital converter for digitising the input signal prior to processing.

14. A system according to claim 12 or 13, including a phase locked loop for determining the fundamental frequency of the input signal by phase locking the input signal on digitisation to the fundamental frequency.

15. A system according to claim 12, 13 or 14, wherein the processing means is operable to determine the real and imaginary parts of the signal.

16. A system according to claim 15, wherein the processing means is operable to determine the real and imaginary parts of the signal by finding the correlation of the

signal with the cosine and sine of each harmonic frequency at each of a plurality of points in time.

17. A system according to claim 16, wherein the processing means is operable to find the correlation of the real part of the signal by multiplication of the signal and a synthesised cosine signal at the given harmonic frequency.

18. A system according to claim 16 or 17, wherein the processing means is operable to find the correlation of the imaginary part of the signal by multiplication with a synthesised sine signal.

19. A system according to any one of claims 12 to 18, including integrating means for integrating the output of the two paths.

20. A system according to any one of claims 12 to 19, including display means operable to display the results of a measurement in graphical form.

21. A system according to claim 20, wherein the display means is operable to generate an Argand diagram.

22. A method of measuring harmonic emissions from electrical apparatus substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

23. A system for measuring harmonic emissions from electrical apparatus substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

The Patent Office

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Application No: GB 0126784.8
Claims searched: 1 to 23

Examiner: Ian Rees
Date of search: 26 June 2002

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): G1U (UR1900, UR2316, UR2320, UR2908, UR3100)

Int Cl (Ed.7): G01R (19/00, 23/16, 23/20, 29/08, 31/00)

Other: Online: EPODOC, WPI, PAJ, INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	GB 2281629 A	POLYMETERS. See claim 2 in particular.	3 to 11, 14 to 23
X, Y	US 5973501	REICHARD. See column 1 (lines 37 to 45) and column 3 (lines 31 to 40).	X: 1, 2, 12, 13 Y: 3 to 11, 14 to 23
X, Y	US 5365164	LOWENSTEIN. See column 1 (lines 8 to 23).	X: 1, 2, 12, 13 Y: 3 to 11, 14 to 23
Y	US 4630229	D'HONDT. See column 3 (line 33) to column 4 (line 31).	3 to 11, 14 to 23
Y	US 4301404	LEY. Note column 3 (lines 50 to 58).	3 to 11, 14 to 23
Y	US 4031462	BOUVIER. See column 3 (lines 26 to 34).	3 to 11, 14 to 23

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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