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(54) Title: CONDITION MONITORING BY CROSS-CORRELATION OF SWITCHING-MODE POWER SUPPLIES

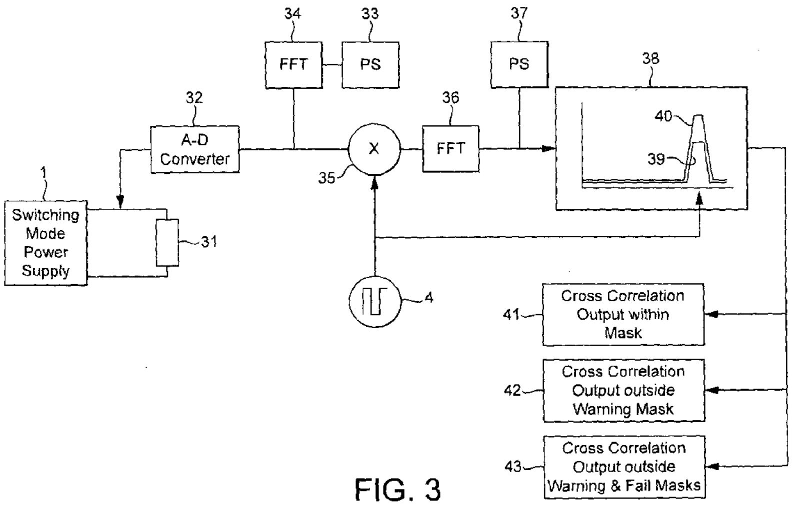

FIG. 3

(57) Abstract: A method of monitoring an output signal of a switching-mode power supply for the presence and magnitude of the switching frequency comprises sampling the output signal at a sampling frequency above the minimum Nyquist limit to provide a succession of samples; cross-correlating a reference signal and the samples to provide cross-correlation values; and monitoring the cross-correlation values to ascertain the magnitude of a component of the output signal at or near the frequency of the reference signal.

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Condition monitoring by cross-correlation of switching-mode power supplies

[0001]

Field of the invention

This invention relates to the condition monitoring of switching-mode power supplies for use in the supply of electrical power to subsea installations.

[0002]

Background to the invention

In recent years attention has been given to the monitoring of systems in order to provide an indication of impending degradation or failure in order that remedial action may be made before actual failure occurs. The general problems are the selection of an appropriate parameter of performance or condition and the selection of an appropriate technique for monitoring changes in that parameter.

[0003]

Power supplies are a ubiquitous part of any electrical or electronic system. They condition an input to supply electrical energy to a load. Historically, power supplies were of a linear type utilising electronic components operating in their linear regions. However, this technology is known to be inefficient. Linear power supply technology, although still used, has largely been superseded by switching mode power supply systems, in which power is dissipated for the most part only when solid state switches such as transistors are transitioning between their 'on' and 'off' states. Such systems are therefore very efficient when compared to 'linear' power supplies. Typically, the switching frequencies are high (50kHz to 1Mhz), allowing the use of small components that result in a very compact power supply.

[0004]

In subsea systems the 'topside' power supply is often designed as an uninterruptible power supply (UPS), wherein an input supply is conditioned and used to charge batteries. The batteries then supply power to a switching regulator that conditions the supply into a suitable form for use subsea. Switching mode power supplies may also be used in subsea power supplies to convert the umbilical supply into lower voltages for subsea electronic modules and, for example, the operation of actuators for valves.

[0005]

Historically, faults in capacitors have been the primary cause of power supply failures. Even with improved manufacturing processes, capacitors continue to cause failures. The lifetime of a capacitor is dependent on voltage, current, and temperature stresses to which it is subjected during its service life. These effects are substantially greater in power supplies than in low-voltage signal processing circuits. As a capacitor ages, its series resistance will tend to increase, resulting in localised heating and thence to localised arching, that ultimately is liable to cause breakdown of a metallized film dielectric. This dielectric breakdown will result in a 'hard' short circuit or open circuit condition and capacitor failure. However, before failure occurs, increase in the series resistance increase affects the performance of the capacitor and thereby in turn will affect the performance of the output filter of the switching mode power supply.

[0006]

Switching power supplies have carefully designed filters that remove as much of the switching frequency from the output as is practically possible. If the performance of the filter reduces because of a capacitor's degradation, more of the switching frequency will appear in the power supply's output voltage than is specified by the manufacturer. Therefore, as the power supply ages, so the amplitude of the switching frequency in the output will increase.

[0007]

State of the art

It is known from US2008/018195 A1 to measure noise in a power supply circuit by generating a sine wave of variable frequency and amplitude and cross-correlating this signal with the noise from the power supply. Other documents which employ cross-correlation in different contexts are US-4430611 and US6424138-B1, which describe spectrum analysers, the document US2004/0206170 A1, which describes the detection of torsional vibrations, and the document EP-1533624-A1, which describes cross-correlation between a test signal and an output signal of an electrical circuit.

[0008]

Summary of the invention

The present invention particularly concerns a technique for monitoring the condition of a switching-mode power supply in reliance on the increase of the switching frequency in the output of the supply.

[0009]

The basis of the invention is a method of monitoring an output of a switching-mode power supply operating at a known switching frequency, comprising: sampling the output of the power supply at a sampling frequency above the minimum Nyquist limit to provide a succession of samples; cross-correlating a reference signal at the switching frequency and the said samples to provide cross-correlation values; and monitoring the cross-correlation values to ascertain the magnitude of a component of the output signal at or near the switching frequency.

[0010]

Preferably the cross-correlation values are in or are converted to the frequency domain signal and the monitoring comprises detecting the magnitude of a component or components within a particular frequency range. The monitoring may employ a plurality of different thresholds for the said magnitude.

[0011]

The sampling frequency may be at least ten times the highest frequency in the output of the switching-mode power supply.

[0012]

The invention extends to a switching mode power supply operating at a known switching frequency, comprising: a series switch; a source of a switching signal operating the switch at a switching frequency; an inductor in series with the switch; a shunt diode forming loop with the inductor and a load; an output filter; means for sampling the output of the power supply at a sampling frequency above the minimum Nyquist limit to provide a succession of samples; means for cross-correlating a reference signal at the switching frequency and the said samples to provide cross-correlation values; and means for monitoring the cross-correlation values to ascertain the magnitude of a component of the output signal at or near the switching frequency.

[0013]

Brief description of the drawings

Figure 1 is a schematic representation of a switching-mode power supply

Figures 2A to 2C illustrate various frequency spectra.

Figure 3 is a schematic representation of one example of the invention.

[0014]

Detailed description

Figure 1 shows a general overview of a switching-mode power supply. There are several different standard designs available. For the purposes of this description a buck design in a basic form is used to illustrate the operation of the switching-mode power supply. The switching circuit 1 receives on input lines 2 an input power signal Vin and is represented by a series switch 3 which is controlled by a switching signal from a source 4 at a predetermined frequency. An input filter represented by a capacitor Cin filters input harmonics and controls the power factor. The switching action, controlled by the switching frequency, provides a stream of pulses on output lines 5 to a load (not shown). The pulse stream is regulated (by the shunt diode 6) and then filtered by the output filter constituted by the series inductor L and the shunt capacitor Cout. The shunt diode provides with the inductor a free-wheeling loop around which current can flow through the load when the switch is open.

[0015]

The filter represented in Figure 1 by the capacitor Cout performs the important functions of filtering out the switching frequency, reducing harmonic distortion on the output voltage, and supplying power to the load, which may be reactive.

[0016]

It should be understood that Figure 1 shows a switchingmode power supply in its basic form. In practice the circuit is more complex. There may be a multiplicity of switches in parallel providing which are connected in series with the load. The filters at both the input and the output may be more complex in order to provide compensation for various effects particularly when coupling transformers are employed.

[0017]

The filtration is normally configured to remove as much of the switching signal's components as feasible. A power spectrum (PS) plot represents a time domain signal in the frequency domain and depicts the proportion of a signals power falling within given frequency range or 'bin'. Therefore in the frequency domain, as a switching power supply ages, so the power of the switching frequency will increase in the associated frequency 'bin'. This increase can be measured and limits or thresholds can be set (through detailed knowledge of the performance of the power supply usually gained through accelerated testing) to detect the switching frequency's power increase and to predict failure before actual failure occurs.

[0018]

Figure 2A is a diagram of the frequency spectrum (magnitude M against frequency f) of the output of the power supply. The spectrum comprises components 21 at or near zero frequency and what should be a small component 22 (encircled) at the switching frequency. Some designs provide for variation of the switching frequency within a small range.

[0019]

Figure 2B is a diagram of the frequency spectrum of the switching source 4. It comprises (for example) a single dominant component 23. Harmonics of the switching frequency which are necessarily present by virtue of the wave shape employed have been omitted.

[0020]

Figure 2C shows a Fourier cross-spectrum obtained by cross-correlating the output of the switching-mode power supply and the known switching signal. It will show a peak 24 dependent on the magnitude of the switching frequency component in the output of the switching-mode power supply. Monitoring the of the magnitude of this peak will provide an indication of degradation of components of the switching-mode power supply, particularly of a capacitor in the output filter.

[0021]

Figure 3 shows a practical implementation of the technique. The switching-mode power supply 1 as shown by way of example in Figure 1 provides an output to a load 31. The output voltage of the switching-mode power supply 1 is sampled, using a sampling frequency substantially above the minimum Nyquist limit and preferably at for example at ten times the highest frequency of interest, with an analogue to digital converter 32 controlled by a sampling clock (not shown). The power spectrum (PS) can be observed on a display 33 at this point if required by transforming to the frequency domain by a stage 34 employing using a discrete Fourier transform, preferably a Fast Fourier Transform (FFT).

[0022]

The sampled output of the switching-mode power supply is then cross correlated with the known switching frequency by means of a cross-correlator 35. This may be of known form. Some switching-mode power supplies use either single or variable switching frequencies. In either case the sampled time domain signal can be cross correlated with the known single frequency or band of frequencies within the known limits of the variable frequencies. The cross-correlation technique is highly sensitive and will produce an amplified output at the switching frequency if the switching-mode power supply has switching frequency components in its output. The larger the amplitude of the switching frequency component in the output of the power supply; the larger is the magnitude of the cross-correlation output.

[0023]

The output of the cross-correlator is transformed to the frequency domain by a stage 36 using a discrete Fourier transform, preferably a fast Fourier Transform (FFT). The power spectrum (PS) of the signal can be observed on a display 37 at this point if required.

[0024]

The stage 38 represents a set of masks which perform both frequency and amplitude discrimination. Two masks 39 and 40 are schematically represented in stage 38. Each is set around the frequency bin containing the power supply switching frequency (or frequencies) of the cross-correlation power spectrum. However, they are set to provide a respective indication when the peak within the frequency range (i.e. in the vicinity of the switching frequency) exceeds a respective threshold. These indications obtained by the masking stage 38 may control the stages 41 to 43. The source 4 may provide a reference signal for selection of the correct masks for the desired frequency bin.

[0025]

Stage 41 indicates that the cross-correlation output in the respective range is within the lower masking threshold (mask 39) and thereby indicates that the power supply condition is satisfactory.

[0026]

Stage 42 indicates that the cross-correlation output in the respective range is above the lower masking threshold but below the upper masking threshold (mask 40). This condition may be regarded as a warning of deterioration which is not yet unsatisfactory.

[0027]

Stage 43 indicates that the cross-correlation output in the respective range is above the upper masking threshold. This condition may be regarded as a failure mode which warrants immediate remedial action.

[0028]

Although the masking technique requires at least one masking threshold, the number of masking thresholds and their magnitudes may be varied according to preference.

[0029]

For simplicity the process of converting a waveform from the time domain to the frequency domain in a form that is suitable for display on a power spectrum chart or as an input to the masking stage is shown as FFT. In actuality a Fast Fourier Transform (FFT) of a time domain signal will result in a two sided complex form. For this example the complex form may transformed to a single sided power spectrum. The phase information may be ignored.

[0030]

Further, for simplicity the switching source 4 is shown as feeding directly into the cross-correlator 36. However, in practice the switching frequency may be sampled by an A-D converter at the same frequency as the output of the switching-mode power supply.

[0031]

Moreover, the cross-correlation may be performed in the time (direct) domain or frequency domain. For small data sets the time domain is more efficient, and for large data sets the frequency domain is more efficient. Figure 3 shows the time domain cross correlation for simplicity.

[0032]

The reference signal at or in the vicinity of the switching frequency for use in the cross-correlation may be obtained directly from the source 4 or may be separately generated.

Claims

1. A method of monitoring an output of a switching mode power supply operating at a known switching frequency, comprising:

sampling the output of the power supply at a sampling frequency above the minimum Nyquist limit to provide a succession of samples;

cross-correlating a reference signal at the switching frequency and the said samples to provide cross-correlation values; and

monitoring the cross-correlation values to ascertain the magnitude of a component of the output signal at or near the switching frequency.

2. A method according to claim 1 in which the cross-correlation values are in or are converted to the frequency domain signal and the monitoring detecting the magnitude of a component or components within a particular frequency range.

3. A method according to claim 2 in which the monitoring employs a plurality of different thresholds for the said magnitude.

4. A method according to any of claims 1 – 3 in which the sampling frequency is at least ten times the highest frequency in the output of the switching-mode power supply.

5. A switching-mode power supply operating at a known switching frequency, comprising:

a series switch (3);

a source (4) of a switching signal operating the switch at a switching frequency;

an inductor (L) in series with the switch;

a shunt diode (6) forming loop with the inductor and a load;

an output filter (Cout);

means (32) for sampling the output of the power supply at a sampling frequency above the minimum Nyquist limit to provide a succession of samples;

means (35) for cross-correlating a reference signal at the switching frequency and the said samples to provide cross-correlation values; and

means (38) for monitoring the cross-correlation values to ascertain the magnitude of a component of the output signal at or near the switching frequency.

6. A switching-mode power supply according to claim 5 wherein the means (38) for monitoring applies a plurality of masks to determine whether the said magnitude exceeds one of a plurality of different thresholds.

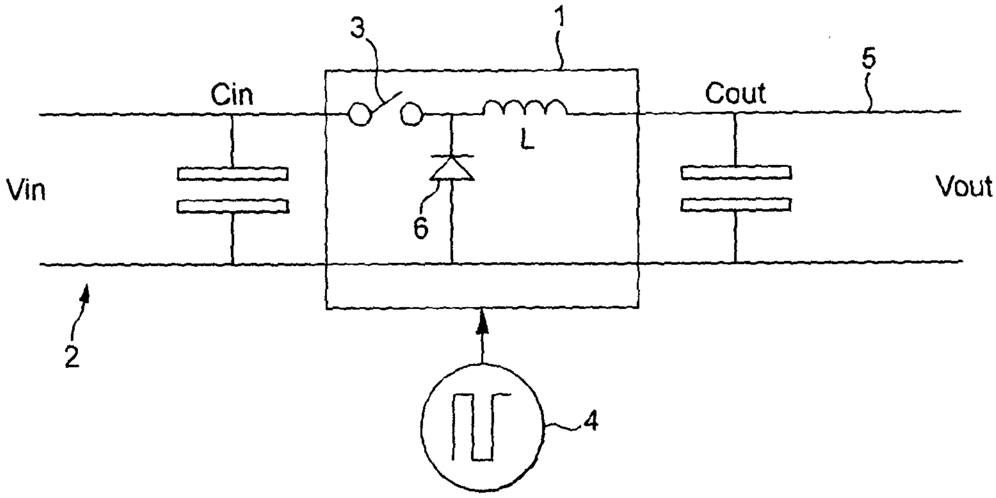

FIG. 1

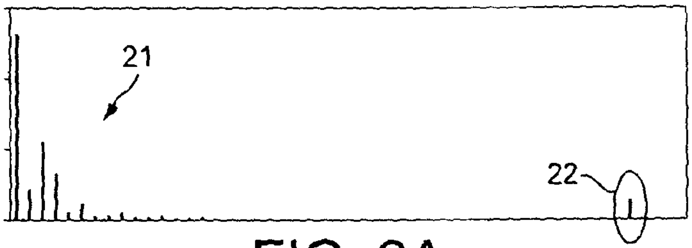

FIG. 2A

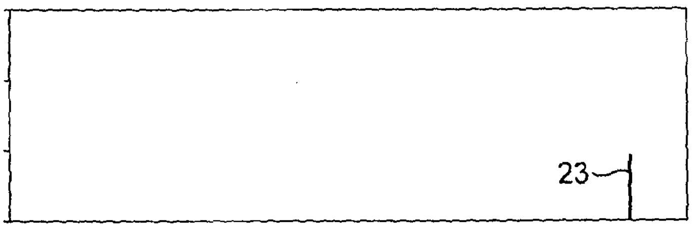

FIG. 2B

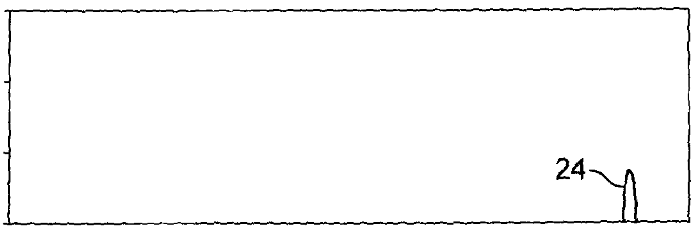

FIG. 2C

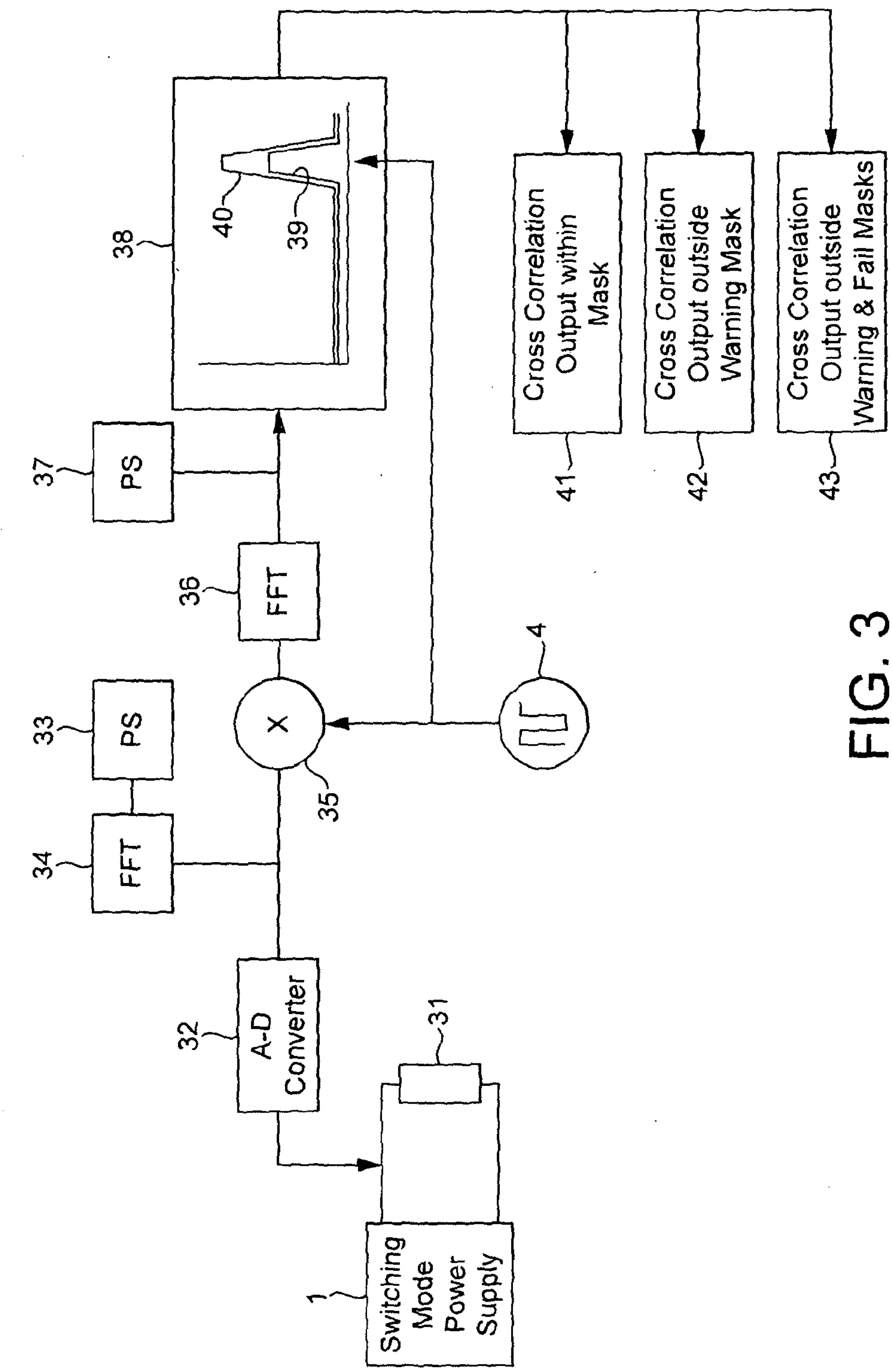
Switching Mode Power Supply
1
31
A-D Converter
32
FFT
34
PS
33
x
35
4
FFT
36
PS
37
38
40
39
Cross Correlation Output within Mask
41
Cross Correlation Output outside Warning Mask
42
Cross Correlation Output outside Warning & Fail Masks
43

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2012/000740

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R31/40
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
10 December 2012	18/12/2012

Name and mailing address of the ISA/	Authorized officer
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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