

BROADCAST CHANNEL TESTING

Technical Field

The present invention relates to a method of, and a testing device for, testing a
5 broadcast channel.

Background

Communication systems for transmitting and/or receiving data across an electric
power grid are known. Transmitting data across an electric power grid is advantageous
10 because it uses existing infrastructure as the transmission medium. Since most premises
that need a communications link are already connected to the electric power grid, a user
may connect to the communications link without any additional infrastructure being
required. Furthermore, the number of users already connected to the electric power
grid, and the number of points at which one can connect to the electric power grid, is
15 large, and therefore the infrastructure of the electric power grid provides a flexible
network over which communication can be established.

Typically, in such a communication system, a data signal comprising a
modulated carrier wave is superimposed onto an AC power signal. Typically, the
superimposed data signal is modulated at a frequency much higher than a grid
20 frequency of the electric power grid. For example, a data signal in the frequency range
kHz to MHz may be superimposed on a mains signal with a grid frequency of nominally
50 or 60Hz.

Such methods for transmitting and/or receiving data within an electric power
grid are often limited in range because conventional power lines that carry the AC
25 power signal and therefore carry the data signal are designed to be efficient at mains
frequencies and tend to attenuate frequencies higher than the grid frequency.

It is an object of the present invention to at least mitigate some of the problems
of the prior art.

Summary

According to a first aspect of the present invention, there is provided a method
of testing a broadcast channel in which information is transmitted within a synchronous

area of an electric power grid in which electric current flows according to a grid frequency, the information being transmitted based on instructions from a control node by modulating the grid frequency to provide a carrier signal having the information encoded therein, the method comprising:

5 measuring, at a testing device, a characteristic relating to a frequency of power flowing in the electric power grid;

 extracting a signal from the electric power grid based on said measured characteristic, the signal being based on a frequency modulation of said grid frequency; and

10 sending, via a second channel different to the broadcast channel, data indicative of a characteristic of the signal for receipt at the control node.

 According to a second aspect of the present invention, there is provided a testing device for testing a broadcast channel, the broadcast channel being one in which information is transmitted within a synchronous area of an electric power grid in which
15 electric current flows according to a grid frequency, the information being transmitted based on instructions from a control node by modulating the grid frequency to provide a carrier signal having the information encoded therein, the testing device comprising:

 a measuring means arranged to measure a characteristic relating to a frequency of power flowing in the electric power grid;

20 a processing means arranged to extract a signal from the electric power grid based on said measured characteristic, the signal being based on a frequency modulation of the grid frequency; and

 a communications interface arranged to send data indicative of a characteristic of the signal for receipt at the control node via a second channel different to the
25 broadcast channel.

 According to a third aspect of the present invention, there is provided a broadcast system comprising:

 a transmitter arranged to transmit a frequency modulated signal via a broadcast channel within a synchronous area of an electric power grid;

30 a testing device according to the second aspect; and

 a control node arranged to communicate with the testing device via the second channel.

Further features and advantages of the invention will become apparent from the following description of preferred embodiments of the invention, given by way of example only, which is made with reference to the accompanying drawings.

5 Brief Description of the Drawings

Figure 1 is a schematic diagram a synchronous electric power grid in which a broadcast system may be implemented;

Figure 2 is a schematic diagram illustrating a transmitter suitable for use in a broadcast system;

10 Figure 3 is a schematic diagram illustrating a receiver suitable for use in a broadcast system;

Figure 4 is a schematic diagram illustrating a test receiver suitable for use in a broadcast system;

15 Figure 5 is a schematic diagram illustrating a controller suitable for use in a broadcast system;

Figure 6 is a flow diagram illustrating a method of testing a broadcast channel; and

Figure 7 is a message sequence chart illustrating data transmissions between components of a broadcast system.

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Detailed Description

The following disclosure relates to broadcasts made in the context of frequency modulated signals broadcast in an electric power grid. However, it will be understood that the invention may be implemented in other types of broadcast system.

25 Figure 1 shows an exemplary electric power grid 100 in which an embodiment of the present invention may be implemented. The electric power grid 100 comprises a transmission grid 102 and a distribution grid 104.

The transmission grid 102 is connected to power generators 106, which may be nuclear plants or gas-fired plants, for example, from which large quantities of electrical
30 energy is transmitted at very high voltages (typically of the order of hundreds of kV), over power lines such as overhead power lines, to the distribution grid 104.

The transmission grid 102 is linked to the distribution grid 104 via a transformer 108, which converts the electric supply to a lower voltage (typically of the order of 50kV) for distribution in the distribution grid 104.

5 The distribution grid 104 is connected via substations 110 comprising further transformers for converting to still lower voltages to local networks which provide electric power to power consuming devices connected to the electric power grid 100. The local networks may include networks of domestic consumers, such as a city network 112, that supply power to domestic appliances within private residences 113 that draw a relatively small amount of power in the order of a few kW. The local
10 networks may also include industrial premises such as a factory 114, in which larger appliances operating in the industrial premises draw larger amounts of power in the order of several kW to MW. The local networks may also include networks of smaller power generators such as wind farms 116 that provide power to the electric power grid 100.

15 Although, for conciseness, only one transmission grid 102 and one distribution grid 104 are shown in figure 1, in practice a typical transmission grid 102 supplies power to multiple distribution grids 104 and one transmission grid 102 may also be interconnected to one or more other transmission grids 102.

Electric power flows in the electric power grid 100 as alternating current (AC),
20 which flows at a system frequency, which may be referred to as a grid frequency (typically the grid frequency is nominally 50 or 60 Hz, depending on country). The electric power grid 100 operates at a synchronized frequency so that the frequency is substantially the same at each point of the grid. The grid frequency varies with the ratio of the total generated power provided to the electric power grid 100 to the total amount
25 of power consumed from the electric power grid 100, referred to herein as a grid power balance. Changes in the grid frequency are due to factors including the operating frequency of turbines in the power generators 106 and the state of tuneable transformers in the electric power grid 100 among others.

The grid frequency typically varies with respect to a nominal grid frequency
30 over time due to normal variations in the grid balance (i.e. variation that is not due to sudden unexpected increases in demand or loss of generation capacity). The normal variation of grid frequency appears as noise with respect to the nominal grid frequency

when the grid frequency is observed over a period of time. The amount of normal variation (hereinafter referred to as noise) in a given synchronous grid is a range of frequencies that depends on the potential energy stored in that synchronous grid (i.e. the inertia of power devices connected to the grid); this may be determined for a given synchronous grid by, for example, making a series of measurements of the grid frequency over a period of time. Grids having higher inertia (i.e. relatively larger amounts of spinning generation) tend to be more stable and therefore less noisy, while grids having lower inertia (i.e. relatively smaller amounts of spinning generation) tend to be less stable and therefore more noisy. For most electric power grids the level of noise is typically in the range of 10 to 200 mHz.

The electric power grid 100 may include one or more direct current (DC) interconnects 117 that provide a DC connection between the electric power grid 100 and other electric power grids. Typically, the DC interconnects 117 connect to the transmission grid 102 of the electrical power grid 100. The DC interconnects 117 provide a DC link between different synchronous electric power grids, such that the electric power grid 100 defines an area which operates at a given, synchronised, grid frequency that is not affected by changes in the grid frequency of other electric power grids. For example, the UK transmission grid is connected to the Synchronous Grid of Continental Europe via DC interconnects.

The electric power grid 100 also includes one or more devices for use in transmission of information (herein referred to as “transmitters” 118) under the control of a control node (referred to herein as a “controller” 122), and one or more receivers 120 capable of receiving information transmitted by the transmitters 118. The transmitters 118, receivers 120, and controller 122 form a broadcast system, in which the electric power grid 100 thereby acts as a broadcast channel between the transmitters 118 and the receiver 120.

Information is transmitted by the transmitters 118 across the broadcast channel for receipt at the receivers 120 by encoding a modulation pattern and superimposing that modulation pattern on the grid frequency as described below with reference to figure 2. The grid frequency thereby acts as a carrier signal for information encoded therein and defined by the modulation pattern. Transmission of information, hereinafter

referred to as data transmission, may be transmission of digital or analogue data and/or other types of information.

The receivers 120 are arranged to decode information encoded in the frequency modulated carrier signal as described below with reference to figure 3.

5 Connected to the electric power grid 100 is a testing device referred to hereinafter as a “test receiver” 121. In the example shown in figure 1, one test receiver 121 is shown. However, it will be understood that multiple test receivers 121 may be connected to the grid and able to receive information from the transmitters 118. As described below with reference to figure 4, the test receiver 121 is arranged to
10 decode information encoded in the frequency modulated carrier signal in the same way as the receivers 120. However, the test receiver 121 has additional functionality enabling it to send data indicative of the signal to the controller 122 via a data channel separate to the broadcast channel, referred to herein as a test channel.

 As explained above, the frequency of electric power is substantially the same
15 across the entire electric power grid 100. Therefore, for practical purposes, a broadcast channel implemented in the electric power grid 100 can be assumed to have the same, or similar, transmission characteristics across the electric power grid 100. This enables an operator of such a broadcast system to manage transmissions over a large geographical area using only one testing device 121, or a small number of testing
20 devices 121 relative to the number of receivers 120. In other words, characteristics of the broadcast channel determined using a test device 121 at one location within the electric power grid 100 (or a limited number of locations) can be representative of the characteristics of the broadcast channel anywhere in the electric power grid 100 where there may be a receiver 120.

25 Each transmitter 118 is associated with a power device 119 (which may consume power from or provide power to the electric power grid 100) or a group of power devices 119 and is located at a connection between the power device 119 (or group of devices 119) and the electric power grid 100. Each transmitter 118 is arranged to modulate a flow of power between the power device 119 (or group of power devices
30 119) and the electric power grid 100. The transmitters 118 may be provided separately to, and/or installed on, the power devices 119. The power devices 119 may be any power consuming or generating devices and may include power generators 106,

appliances in residential premises 113 or industrial premises 114 and/or a small-scale power generators such as wind turbines 116 or solar panels.

The one or more transmitters 118 may be located at power devices 119 in the distribution grid 104 or in the transmission grid 102, or at any other location of the electric power grid 100. The transmitters 118 operate with the power devices 119 to transmit data within the electric power grid 100. Although, for the sake of simplicity, only seven transmitters 118 are shown in Figure 1, it will be understood that, in practice, the electric power grid 100 may comprise hundreds or thousands of such devices, depending upon the capacity of power devices 119 with which the transmitters 118 are associated. Where transmitters 118 are associated with large capacity power devices 119 (such as a power device in an industrial premises) there may only be a small number of transmitters 118. In some embodiments, there may only be one transmitter 118.

The transmitters 118 at the connections each modulate the flow of power between respective associated power devices 119 and the electric power grid 100 according to the modulation pattern defined. Each of the one or more transmitters 118 is synchronised with each of the other transmitters 118 and is arranged to modulate power flow that the transmitters 118 cause a collective modulation of the power flow in the electric power grid 100. That is, the transmitters 118 collectively cause a modulated change in power balance in the electric power grid 100, the change in power balance being the combined effect of the modulated power flow to/from each of the power devices 119 that have an associated transmitter 118.

In modulating the power flowing between a power device 119 and the electric power grid 100, thereby modulating the grid balance, according to the modulation pattern, the transmitter 118 is able to encode the modulation pattern and superimpose that modulation pattern on the grid frequency for transmission across the electric power grid 100. The grid frequency thereby acts as a carrier signal for information encoded therein and defined by the frequency modulation pattern.

Figure 2 shows an exemplary arrangement of a transmitter 118 for transmitting data within an electric power grid 100. The transmitter 118 operates with one or more power devices 119 to transmit data within the electric power grid 100 and comprises a clock 202, a data store 204, a network interface 206, a processor 208, and a modulator 210.

The transmitter 118 is arranged to receive data from the controller 122. The controller 122 may not be directly connected to the electric power grid 100 but instead the data may be received via the network interface 206. The network interface 206 is arranged to receive information via a fixed or wireless communications network, which
5 may include one or more of Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE), fixed wireless access (such as IEEE 802.16 WiMax), and wireless networking (such as IEEE 802.11 WiFi).

Information received via the network interface 206 may be stored in the data
10 store 204. Information stored in the data store 204 may include representations of data that is to be transmitted by the transmitter 118 (referred to herein as “codes”). The codes may represent control signals for controlling the modulator 210 according to a predefined control pattern.

The processor 208 is arranged to retrieve data that is to be transmitted from the
15 data store 204 and to generate control signals for controlling the modulator 210. The processor 208 accesses the data store 204, retrieves a code and, based on the code, generates control signals and sends those control signals to the modulator 210 to control power flow to/from a power device 119. The control signals may be in the form of a bit pattern of data that is to be transmitted in the electric power grid 100. The code
20 typically defines a time-varying pattern of control signals provided with reference to the clock 202. The clock 202 may be synchronised with the clocks of other transmitters 118 in order that each of the transmitters 118 connected to the electric power grid 100 is synchronised with each of the other transmitters 118. This enables transmissions of data to be initiated at each transmitter at the same time.

Each of the transmitters 118 may include a counter, which may be implemented
25 by the processor 208, for counting the cycles of alternating current flowing in the electric power grid 100. The cycles may be identified by cycle numbers that are defined with reference to a defined event or point in time. For example, the cycle number may correspond with the number of cycles of alternating current that have elapsed since the
30 defined event or point in time. Data transmission by the transmitter 118 may be performed at scheduled times with reference to the cycle number (that is, at predetermined cycle numbers that are known to the transmitters 118 and the receivers

120), in order that the transmitters 118 may transmit data at cycle numbers at which the receivers 120, which operate according to the same time-base, expect to receive data; that is, the transmitters 118 and receivers 120 are synchronised.

The modulator 210 is arranged to modulate power flow between a power device
5 119 and the electric power grid 100 in response to the control signals generated by the processor 208. The modulator 210 may comprise a switch for connecting/disconnecting the power device 119 to/from the electric power grid 100 and/or any electrical or electronic means allowing power flow to/from the power device 119 to be modulated. For example, the modulator 210 may comprise an electro-mechanical or
10 semiconductor-based switch. For example, the power device 119 may not necessarily be completely turned off during modulation but may instead be modulated between set points of power consumption and/or provision. The modulator 210 may be an attenuator or some other means for altering the power consumption/provision by the power device 119 (for example, inverter-based chargers for electric vehicles and/or
15 other electric devices, grid-tie inverters for photovoltaic generators, Combined Heat and Power (CHP) generators, or wind generators. The transmitters 118 may be arranged to modulate a reactive power flow to and/or from their associated power devices 119. For example, the modulator 210 may include inverters for modifying a reactive power contribution of their associated power devices 119. Modulating the
20 reactive power contribution of the power devices causes a local modulation of the efficiency of the electric power grid 100 with a corresponding modulation of the available real power.

In modulating the power flowing between a power device 119 and the electric power grid 100 according to the pattern of control signals stored in the data store 204,
25 the modulator 210 is able to encode a frequency modulation pattern and superimpose that modulation pattern on the grid frequency for transmission across the electric power grid 100. The grid frequency thereby acts as a carrier signal for information encoded therein and defined by the modulation pattern.

The modulator 210 is typically arranged to modulate power flow between the
30 power device 119 and the electric power grid 100 at a frequency typically up to 10 Hz. In some embodiments, power flow to and/or from a power device 119 is modulated at a frequency less than half of the predefined grid frequency. In some embodiments,

power flow is modulated at a frequency less than a quarter of the predefined grid frequency. In some embodiments, power flow is modulated at a frequency less than a tenth of the predefined grid frequency. For example, a modulator 210 may be arranged to modulate power flow at a rate of approximately 1 Hz.

5 At this frequency range, switching of moderately high loads is possible. Because the modulator 210 modulates power flow to/from the power device 119 at a frequency less than the grid frequency, the modulated signal is not inhibited by the infrastructure of the electric power grid 100 any more than an un-modulated AC electrical power would be. This removes the need to provide an additional route around
10 devices such as transformers 108, 110.

 Although the transmitter 118 is shown in figure 2 as being separate to the power device 119, it will be understood that in some embodiments the transmitter 118 may be integral to power device 119.

 It should be noted that, although the codes are described above as being stored
15 in the data store 204 of the transmitter 118, in some embodiments they may be stored remotely (for example at the controller 122) and accessed by the transmitter 118 when required. For example, the codes may be transmitted to the transmitter 118, in which case they may not be stored at the transmitter 118, or stored only in a temporary data store.

20 A modulated power flow between the power device 119 and the electric power grid 100 causes a modulation of the balance between power supply and consumption in the electric power grid 100. This in turn causes a corresponding modulation of the grid frequency, which is the same throughout a given synchronous electric power grid 100. Since the grid frequency is the same throughout the electric power grid 100, the
25 modulated frequency is also the same throughout the electric power grid 100 and so are able to detect the modulated grid frequency (such as a receiver 120) and decode the encoded information is able to that at any point in the grid at which it can detect the grid frequency.

 Figure 3 is a diagram illustrating an exemplary receiver 120 configured to
30 decode information encoded in a carrier signal and transmitted within an electric power grid 100. The receiver 120 comprises a detector 302, a data store 304, a processor 306, an input-output (I/O) interface 308, and a clock 310.

The detector 302 may be any device capable of detecting or measuring a characteristic relating to the grid frequency with sufficient precision.

In some embodiments, a time period relating to the grid frequency is used as a characteristic measure of the grid frequency. For example, a measurement of the half-cycle, which is the period between times at which the voltage crosses 0V, may be used
5 as a characteristic relating to the grid frequency.

In some embodiments, the actual instantaneous grid frequency, corresponding to the inverse of the time it takes to complete a half-cycle (or a full-cycle) may be determined. The frequency data may be equalised and digitally filtered to remove
10 frequency components outside a known and desired range of signal frequencies. For example, frequency components corresponding to the grid frequency and/or frequency components relating to noise may be removed.

The detector 302 may comprise a voltage detector arranged to sample the voltage at a frequency higher than the grid frequency and an analogue to digital
15 converter arranged to convert the sampled voltage to a digital voltage signal. For example, the voltage detector may be arranged to sample the voltage 1000 times per cycle. The digital voltage signal may then be processed to determine with a high degree of precision (within the range μ s to ms) the times at which the voltage crosses 0V.

The detector 302 may comprise a current detector arranged to sample the current
20 at a frequency higher than the grid frequency, and an analogue to digital converter arranged to convert the sampled current to a digital current signal, which may then be processed to determine with a high degree of precision (within the range μ s to ms) the times at which the current crosses 0V.

The detector 302 may comprise both a voltage detector and a current detector.
25 Measuring the times at which both the voltage and current crosses 0V enables the receiver 120 to determine a change in the relative phase of the voltage and current, thereby enabling the receiver 120 to compensate for changes in reactive power in the grid. This in turn enables a more accurate measurement of frequency (or a characteristic relating to frequency).

30 An exemplary method of determining the frequency comprises sampling the alternating voltage at a high rate (for example at a rate of 40kHz). A trigger level is chosen at which level the sinusoidal voltage waveform is approximately linear. This is

typically greater than 0V and may be, for example, between 5V and 50V. The time between two consecutive sinusoidal cycles is determined on the basis of the difference between consecutive times at which the alternating voltage reaches the trigger level. This is repeated multiple times (several thousand times, for example) and an average
5 time is then determined. The average time value is then inverted to determine the frequency.

The data store 304 may store data indicative of one or more predetermined code patterns that relate to modulation patterns that the receiver is likely to receive. The processor 306 may use the stored data pattern format to aid extraction, or decoding, of
10 the information from the measured frequency characteristic.

For example, the processor may be arranged to perform a correlation process to determine a correlation between a portion of the modulation pattern (superimposed on the grid frequency) and one of the stored predetermined code patterns. Alternatively, the receiver 120 may include a dedicated correlator arranged to perform the correlation
15 process. The correlation process may, for example, comprise correlating a time-base of the modulation pattern with a time-base of the one or more predetermined code patterns and/or correlating a bit pattern of the modulation pattern with a bit pattern of the one or more predetermined code patterns. The correlation process may comprise determining a probability that the measured frequency characteristic contains a
20 modulation pattern corresponding to a stored predetermined code pattern. The information encoded in the measured frequency signal may then be decoded on the basis of the determined correlation. This enables the information to be decoded even when the magnitude of the modulation (which could be in the range of μHz up to several mHz) is less than the level of noise in the measured grid frequency (which is typically in the range of 10 to 200 mHz, though these typical values vary significantly from one
25 synchronous grid to another and in a given synchronous grid over time). Furthermore, modulating frequency by such a small degree with respect to the noise in the grid (i.e. the normal variation of grid frequency), and the limits agreed by grid operators, provides the possibility of using a large number of distinguishable states to which the
30 frequency can be modulated without triggering a frequency stabilising response and/or disrupting the normal operation of the grid.

The receiver 120 may, on the basis of the correlation process, identify synchronisation data transmitted in the broadcast signal. Based on the identified synchronisation data, the receiver 120 may then determine a start time, which may be a fixed reference time from which the receiver 120 can monitor a number of cycles of the electric power flow in the grid have elapsed. Then after a predetermined number of cycles have elapsed from the start time, the receiver 120 can begin to extract payload data encoded in the carrier signal.

Although the predetermined code patterns are described above as being stored in the data store 304 of the receiver 120, in some embodiments they may be stored remotely (for example at the controller 122) and accessed by the receiver 120 when required. For example, the predetermined code patterns may be transmitted to the receiver 120, in which case they may not be stored at the receiver 120, or stored only in a temporary data store.

The data store 304 may be used to store decoded information that has been transmitted within the electric power grid 100 via the broadcast channel. Furthermore, the data store 304 may store an identifier that identifies the receiver 120 or may be used to address the receiver 120. The identifier may also be included in the modulation pattern by the transmitters 118. The processor 306, may determine from information in a received transmission whether the transmission relates to the receiver 120 by comparing the identifier stored in the data store 304 with identification information included in the modulation pattern. If the processor 306 determines that the received data is for the receiver 120, the processor 306 may then continue to process and store the decoded information.

The data store 304 may store one or more other identifiers that identify groups to which a receiver 120 is assigned. Transmissions intended for receipt by particular groups may include the identifiers associated with those groups to enable the receivers 120 in the groups to determine whether they are intended to receive the transmission. This may be achieved by determining a correspondence between a transmitted identifier and the one or more identifiers stored in the data store 304 of the receiver 120.

In some embodiments, groups may be defined for different geographical areas. Each group corresponding to a geographical area may be divided into sub-groups relating to smaller areas within a given geographical area. For example, a group may

be defined for all the receivers in a particular country, and sub-groups may be defined for each region in that country. Receivers 120 in a particular region of the country may store identifiers relating to the group and sub-group corresponding to their particular location (that is, their country and region) so that data may be addressed to all receivers 120 in a particular country or region.

The processor 306 may be any processor capable of processing received data. The processor may include, but not be limited to, one or more of an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), a digital signal processor (DSP), and a general-purpose programmable processor.

The processor 306 may be arranged to perform error detection and error correction functions on data that is received over the electric power grid 100. The processor 306 may be arranged to decrypt received data where that data has been encrypted.

Once data has been received and processed by the receiver 120 it may be output to an intended recipient of the data via the I/O interface 308. The I/O interface 308 may be arranged to display information on, for example, a display of a computer or of the receiver 120 itself.

The receiver 120 keeps its timing by counting the cycles of alternating current flowing in the electric power grid 100; for example, the receiver 120 may include a counter, which may be implemented by the processor 306. Where the receiver 120 is temporarily unable to count the cycles of alternating current (for example, during brief power outages), the clock 310 is able to maintain the timing of the receiver 120 to enable the processor 306 to remain synchronised for at least a few cycles. This enables the receiver 120 to continue to receive and process data during periods when it is temporarily unable to count the cycles of alternating current.

The detector 302 may be arranged to detect the grid frequency indirectly by detecting so-called grid noise from electrical appliances connected to the electric power grid 100. For example, the receiver 120 may be a wireless communication device suitably programmed to detect electromagnetic or audio signals (corresponding to frequency variation) emitted by electrical appliances connected to the electric power grid 100, and process those signals to determine the grid frequency as described above. In certain embodiments, the receiver may be a Personal Digital Assistant (PDA), a

Smartphone, or a portable computer running a computer program (such as an application) programmed to receive and process data transmitted by the transmitters 118.

Figure 4 is a diagram illustrating an exemplary test receiver 121. The test receiver 121 is configured to decode information encoded in a carrier signal and transmitted within an electric power grid 100 in the same way as, or a similar way to, the receivers 120. Therefore, the test receiver 121 also comprises a detector 302, a data store 304, a processor 306, an input-output (I/O) interface 308, and a clock 310. The detector 302, data store 304, processor 306, input-output (I/O) interface 308, and clock 310 may operate as described above in relation to the corresponding features of the receiver 120 and are not discussed further for conciseness.

The test receiver 121 also includes a communications interface 402 which it uses to communicate with the controller 122 via a second communications medium, which may be different to the electric power grid 100, such as a fixed or wireless communications network. The test channel is a communications channel between the test receiver 121 and the controller using the second communications medium. The test channel may include one or more physical or logical channels. The communications network may include one or more of a cellular network, a wireless local area network, a wired local area network, a wide area network, a wired telecommunications network, and the internet. The communications network may include one or more of Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE), fixed wireless access (such as IEEE 802.16 WiMax), and wireless networking (such as IEEE 802.11 WiFi and IEEE 802.15 ZigBee). In some embodiments, the test receiver 121 may be a dedicated testing device. In other embodiments, the test receiver 121 may be a receiver 120 modified or adapted to include the functionality of a testing device. In either case, the test receiver 121 may also be able to perform as a normal receiver 120.

The test receiver 121 may use the communications interface 402 to send and/or receive data to and/or from the controller 122. For example, the test receiver 121 may send and/or receive data to and/or from the controller 122 via the Internet. The communications may be based on the Internet Protocol. The test receiver 121 may pull data from the controller 122 or may receive data pushed from the controller 122. The

test receiver 121 may use data received from the controller 122 via the test channel to evaluate the signal extracted from the broadcast channel of the electric power grid 100.

Received data may be stored or buffered in the data store 304 to be used later. For example, the data may be acted upon only at a predetermined time indicated by a
5 time indicator that is transmitted either with the data or in a separate transmission.

The processor 306 of the test receiver 121 may, for example, execute programs stored in its data store 304 for performing functions relating to testing of the broadcast channel, including functions for performing the methods described below with reference to figures 6 and 7.

10 Figure 5 is a diagram illustrating an exemplary controller 122 for controlling transmissions of data in the electric power grid 100. The controller 122 manages broadcasts that are to be transmitted by the transmitters 118. The controller 122 may include one or more servers located in a control centre. The controller 122 may be arranged to receive requests from users wishing to transmit data across the electric
15 power grid 100 and, in response to receiving such requests may configure data packets to be transmitted.

The controller 122 comprises a processor 502, a data store 504, a user interface 506, a clock 508, and a network interface 510.

20 The data store 504 may be used to store data that is to be transmitted within the electric power grid 100.

The data store 504 may also include a database containing records of deployed receivers 120 and/or test receivers 121. The records may include information including identifiers of the receivers 120 (that may be used to address particular receivers 120), device capabilities, information about the configurations of the receivers 120 (such as
25 a current software version operating on the receiver 120 or a current broadcast schedule stored at the receiver 120), information about the location of receivers 120 and information about other devices connected to the receivers 120 (such as the power devices 119) and the capabilities of these connected other devices.

30 The data store 504 may include information about the grouping of receivers 120, and may store identifiers that may be used by the controller 122 to manage groups of receivers 120, and to send data to an addressed group of receivers 120.

Users (for example, owners) of a receiver 120 may be able to register their receiver 120 in the data store 504 via the user interface 506. Users may also upload messages that are to be transmitted via the user interface 506. For example, the user interface 506 may be a client interface accessible by the users via the internet 126.

5 Information relating to messages that are to be transmitted, such as the date and time when the message is to be transmitted, and the recipients of the message may also be entered and stored in the data store 504 via the user interface 506.

Each registered receiver 120 may be assigned to one more groups of receivers 120. Each group that a given receiver 120 is assigned to may have a corresponding

10 identifier that is stored in a record associated with the given receiver 120. As described above with reference to figure 3, the one or more identifiers may also be stored in the data store 304 of the respective receiver 120, and may be used to determine whether received data is intended for receipt at that receiver 120.

The processor 502 is arranged to retrieve data from the data store 504 and form

15 messages that are then transmitted to the transmitters 118. The controller 122 may be able to connect to the transmitters 118 via a wired or wireless connection. For example, the controller may connect via the network interface 510 to a wireless access node 124 using one or more of a number of radio access technologies including Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System

20 (UMTS), Long Term Evolution (LTE), fixed wireless access (such as IEEE 802.16 WiMax), and wireless networking (such as IEEE 802.11 WiFi and IEEE 802.15 ZigBee). As described above, the controller 122 may transmit data to the transmitters 118 via a data communications network such as the Internet 126. The controller 122 may not have any direct electrical power connection to the electric power grid 100.

25 Based on data retrieved from the data store 504, the processor is also arranged to generate data indicative of messages that are transmitted to the transmitters 118 to be transmitted via the broadcast channel. The controller 122 may send such generated data to the test receiver 121. The controller 122 may connect to the test receiver 121 (or test receivers) via a wired or wireless connection as described above in relation to its

30 connection with the transmitters 118.

Data may be communicated to the transmitters 118 and the test receiver 121 using any appropriate data transmission protocol such as, for example, but not limited

to, Transmission Control Protocol (TCP), User Datagram Protocol (UDP) or 6LoWPAN protocol.

At the required time (or in advance of the required time) the controller 122 may transmit messages including the data that is to be transmitted to one or more transmitters 118 in the electric power grid 100. The one or more transmitters 118 may then each receive the data that is to be transmitted and, at the appropriate time begin transmitting the data within the electric power grid 100.

The controller 122 may also transmit data indicative of the data that is to be transmitted to the test receiver 121.

The transmitters 118 and/or the test receivers 121 may connect to and poll the controller 122 to check if the controller 122 has any new data that needs to be transmitted. This provides additional security to the transmission because data is only received by the transmitters 118 and/or receivers 121 when they actively look for data from trusted sources.

In order that each of the transmitters 118 is synchronised with each of the other transmitters 118, the controller 122 may also transmit synchronisation signals to the transmitters 118. However, the transmitters 118 may be synchronised according to some other signal; for example, the transmitters 118 may be synchronised using one or more of a GPS signal, an internet network time, or a low-frequency radio clock signal based on a time from an atomic clock such as, for example, the “MSF” radio time signal from the National Physical Laboratory in the UK. The transmitters 118 therefore are able to share a common time base, which is used when transmitting signals to the receivers 120.

In some embodiments, transmission of data is performed according to a broadcast schedule. Different types of data may be broadcast at different, pre-agreed, times according to the broadcast schedule. The transmitter 118 and/or the receiver 120 may be pre-programmed or hard-wired with the broadcast schedule so that it may receive particular types of data at the relevant times once synchronised. The broadcast schedule may be provided to the transmitters 118 and/or the receivers 120 by the controller 122. The transmitters 118 might provide the broadcast schedule to the receivers 120. The receivers 120 may then perform their correlation processes only at, or around, the scheduled times.

Figure 6 depicts a method 600 of testing a broadcast channel such as that implemented in an electric power grid comprising a controller 122, transmitters 118, receivers 120 and one or more test receivers 121.

At step S602, the test receiver 121 measures a characteristic relating to a frequency of power flowing in the electric power grid 100.

At step S604, the test receiver 121 extracts a signal from the electric power grid based on the measured characteristic. The signal is based on the frequency modulation pattern encoded in and superimposed on the grid frequency. That is, the signal comprises data broadcast over the broadcast channel.

At step S606, the test receiver 121 sends data indicative of a characteristic of the extracted signal to the controller 122. The data is sent via a different channel to the broadcast channel.

The controller 122 may transmit to the test receiver 121 (via the test channel) data indicative of data that was, or is to be, transmitted to the receivers 120 over the broadcast channel. The processor 306 of the test receiver 121 may be configured to compare an extracted signal (i.e. data received via the broadcast channel) with the data received via the test channel and may determine a quality characteristic of the broadcast channel on the basis of the comparison. For example the processor 306 may determine a measure of the quality of the extracted signal and/or the broadcast channel on the basis of the comparison.

The processor 306 may be configured to generate data indicative of the determined quality characteristic for transmission via the communications interface 402 to the controller 122, at step S606.

In a particular example, the controller 122 may send data indicative of data that is to be transmitted via the broadcast channel to the test receiver 121 prior to transmitting the data over the broadcast channel for receipt at the receivers 120. When the information is broadcast over the broadcast channel, it can be received by the receivers 120 and the test receiver 121. The test receiver 121 is then able to use the information decoded from the signal broadcast over the broadcast channel and the data received over the test channel to evaluate the quality of the broadcast channel. For example, the processor 306 of the test receiver 121 may be programmed to measure or

calculate a quality characteristic of the transmission it decodes to generate an estimate of the quality characteristic of the transmission received by the receivers 120.

Figure 7 shows communications between the controller 122, test receiver 121 and transmitter 118 in an exemplary method 700 of testing the broadcast channel in order to optimise broadcasts made via the broadcast channel.

At step S702, the controller 122 transmits data to the test receiver 121 via the test channel. The data indicates to the test receiver 121 the information that is to be encoded in a signal broadcast via the broadcast channel.

At step S704, the controller 122 sends a command to the transmitter 118 (or transmitters 118) to encode information corresponding to the information indicated to the test receiver 121 in a modulation pattern so as to superimpose the modulation pattern information on the grid frequency.

At step S706, the transmitter 118 broadcasts the information by encoding it in and superimposing it on the grid frequency.

At step S708, the test receiver 121 extracts the signal and decodes the information encoded therein. The test receiver 121 then evaluates the signal extracted from the electric power grid 100 with respect to the data it received from the controller at step S702. Based on the result of the evaluation, the processor 306 of the test receiver 121 determines a quality characteristic of the broadcast channel.

The evaluation performed by the processor 306 of the test receiver 121 to determine the quality characteristic may include one or more of: determining a signal-to-noise ratio of the extracted signal on the basis of the extracted signal and the received data; detecting bit errors within the extracted signal on the basis of the extracted signal and the received data; identifying error coding data encoded within the signal and performing an error checking process using the error coding data; and identifying interference in the channel on the basis of the extracted signal and the received data. The error checking process may include, for example, a cyclic redundancy check. In such an error checking process, the processor 306 of the test receiver 121 may assign a confidence value to respective bits of the extracted signal.

At step 710, the test receiver 121 sends data indicative of the quality characteristic determined at step S702 to the controller 122 via the test channel.

At step S706, the controller 122 receives the data indicative of the quality characteristic.

At step S712, on the basis of the received quality characteristic, the controller determines that a change of one or more characteristics of transmission via the broadcast channel is needed.

At step S714, to initiate the necessary change, the controller 122 sends further commands to the transmitter 118 implementing the changes to the characteristic of transmission. The further commands may include changes to one or more of: a forward error correction redundancy of a transmitted signal, a signal strength of a transmitted signal, a characteristic relating to length of a transmitted signal, information encoded in a transmitted signal, a bit coding length of a transmitted signal, a characteristic relating to length of a cyclic redundancy check of a transmitted signal, and power flowing to and/or from one or more transmitters

By changing the characteristics of transmissions, the controller 122 can attempt to optimise the balance between the use of resources (such as the power of transmission, or the amount of bandwidth utilised for error detection/correction) with transmission quality for a given broadcasting environment. This enables a significant increase in data throughput and/or more efficient use of the resources. In particular, the amount of transmission power utilised to send a transmission via the broadcast channel can be minimised while maintaining a desired broadcast transmission quality.

For example, the controller 122 may issue instructions or commands to one or more of the transmitters 118 to change one or more of: a forward error correction redundancy of a transmitted signal; a signal strength of a transmitted signal; a characteristic relating to length of a transmitted signal; information encoded in a transmitted signal; a bit coding length of a transmitted signal; a characteristic relating to length of a cyclic redundancy check of a transmitted signal; and power flowing to and/or from one or more transmitters.

The controller 122 may alternatively or additionally, instruct the transmitters 118 to resend a transmission via the broadcast channel. For example, where the quality characteristic determined on the basis of an initial broadcast has a value (such as a value of signal to noise ratio, for example) that is below a predetermined threshold value, the

controller 122 may determine that the quality of the initial broadcast is not sufficient and may therefore attempt to resend the broadcast.

In some implementations, the number of times an initial broadcast can be resent may be limited in order to prevent or minimise resources being dedicated to transmissions that are unlikely to be successful. In such implementations, the controller 122 may be configured to increase the limit on the number of retransmission attempts that are allowed in response to determining that the quality characteristic has a value below the predetermined threshold. Conversely, the controller 122 may be configured to decrease the limit on the number of retransmission attempts that are allowed in response to determining that the quality characteristic has a value exceeding the predetermined threshold.

In cases where the quality characteristic indicates that the data received via the broadcast channel contained erroneous bits, the controller may again be configured to initiate resending of the erroneous data.

In some examples, the processing power of the processor 306 and the speed of the communications interface 402 may be designed such that data relating to the quality characteristic may be sent to the controller 122 via the test channel during the transmission via the broadcast channel. This enables the controller 122 to control the transmission over the broadcast channel in real time using the test channel as a feedback loop. Such real-time optimisation of transmissions sent via the broadcast channel enables a further increase in data throughput and/or more efficient use of resources (such as the power of transmission, or the amount of bandwidth utilised for error detection/correction). Furthermore, it enables these advantages in a changing broadcasting environment. For example, the controller 122 can adapt the characteristics of transmissions via the broadcast channel in response to variations in inertial “stiffness” of the electric power grid 100 on, for example, a seasonal, weekly, or daily basis. The controller can also adapt to changing noise environments as, for example, power providers or consumers connect to or disconnect from the electric power grid 100. This enables the amount of transmission power utilised to send a transmission via the broadcast channel can be minimised while maintaining a desired broadcast transmission quality.

Furthermore, the quality characteristic sent to the controller 122 via the test channel can be used to identify interfering transmissions and in particular, rogue (unauthorised) transmissions. For example, the controller 122 may detect a transmission that it had not initiated and thereby determine that the transmission is unauthorised. For transmissions sent at a rate of the order of ~ 1 bps, the controller may detect an unauthorised transmission before that transmission had completed. In response to determining that a transmission is unauthorised, the controller 122 may take an action to protect the security of the broadcast system. For example, the controller 122 may raise an alarm notifying an operator of the broadcast system of the unauthorised transmission.

In some implementations, the broadcast system may include multiple test receivers 121. This may enable testing of multiple broadcast channels (for example, channels being used by different broadcast systems in the same grid) simultaneously. The multiple test receivers 121 may be distributed across the electric power grid 100. This may enable the controller 122 to assess local variation in the quality of the broadcast channel and/or perform statistical analyses on the data provided by the distributed test receivers 121. This may enable the controller 122 to improve the accuracy with which the estimates of the quality of the broadcast channel (as seen by the receivers 120) can be made.

The above embodiments are to be understood as illustrative examples of the invention. Further embodiments of the invention are envisaged. For example, the test receiver 121 may not be arranged to perform any evaluation or analysis of the extracted signal and may instead communicate data indicative of the extracted signal to the controller, via the test channel, for the controller to analyse. The controller 122 may then perform the evaluation with respect to the data it intended to be transmitted via the broadcast channel.

Although, in the embodiments described above, the receivers 120 and the test receivers 121 are described as separate entities, it will be understood that the test receivers may also act as receivers. In some implementations, a receiver 120 (or a relatively small number of receivers 120) may be modified or adapted to perform the functions of a test receiver 121.

Although the test channel is described for the purposes of sending data relating the quality of the broadcast channel, it will be understood that other data may be communicated between the controller 122 and the test receiver 121. For example, the test channel may be used to monitor the speed of transmission by knowing when a transmission is sent and notifying the controller 122, via the test channel, when the
5 transmission is received by the test receiver 121.

It is to be understood that any feature described in relation to any one embodiment may be used alone, or in combination with other features described, and may also be used in combination with one or more features of any other of the
10 embodiments, or any combination of any other of the embodiments. Furthermore, equivalents and modifications not described above may also be employed without departing from the scope of the invention, which is defined in the accompanying claims.

CLAIMS

1. A method of testing a broadcast channel in which information is transmitted within a synchronous area of an electric power grid in which electric current
5 flows according to a grid frequency, the information being transmitted based on instructions from a control node by modulating the grid frequency to provide a carrier signal having the information encoded therein, the method comprising:

measuring, at a testing device, a characteristic relating to a frequency of power flowing in the electric power grid;
10 extracting a signal from the electric power grid based on said measured characteristic, the signal being based on a frequency modulation of said grid frequency; and
sending, via a second channel different to the broadcast channel, data indicative of a characteristic of the signal for receipt at the control node.

15

2. A method according to claim 1, comprising:
evaluating the extracted signal with reference to data received via the second channel and stored at the testing device to determine a quality characteristic of the broadcast channel; and
20 sending data indicative of the determined quality characteristic for receipt at the control node.

3. A method according to claim 2, wherein the evaluation comprises one or more of:

25 determining a signal-to-noise ratio of the extracted signal on the basis of the extracted signal and the data received via the second channel;

detecting bit errors within the extracted signal on the basis of the extracted signal and the data received via the second channel;

30 identifying error coding data encoded within the signal and performing an error checking process using the error coding data; and

identifying interference in the channel on the basis of the extracted signal and the data received via the second channel.

4. A method according to claim 2 or claim 3, comprising receiving, at the control node, the data indicative of the quality characteristic of the broadcast channel and initiating a change of one or more characteristics of transmission via the broadcast
5 channel on the basis of the quality characteristic.

5. A method according to claim 4, wherein the one or more characteristics of transmission comprises one or more of:

- a forward error correction redundancy of a transmitted signal;
- 10 a signal strength of a transmitted signal;
- a characteristic relating to length of a transmitted signal;
- information encoded in a transmitted signal;
- a bit coding length of a transmitted signal;
- a characteristic relating to length of a cyclic redundancy check of a transmitted
15 signal; and
- power flowing to and/or from one or more transmitters.

6. A method according to any of claim 2 to claim 5, comprising resending the transmission via the broadcast channel in response to a determination that the
20 quality characteristic has a value below a predetermined threshold value.

7. A method according to claim 6, comprising increasing a maximum number of allowed retransmission attempts in response to a determination that the quality characteristic has a value below the predetermined threshold.
25

8. A method according to any of the preceding claims, wherein the information is encoded in a carrier signal and transmitted within a synchronous area of an electric power grid, the carrier signal comprising an alternating current, or alternating voltage, of electric power flowing in the electric power grid in accordance with a grid
30 frequency, the method comprising:

- accessing data indicative of one or more predetermined code patterns;

performing a correlation process, at the testing device, to determine a correlation between at least a portion of a modulation pattern of the measured frequency characteristic and at least one of the one or more predetermined code patterns, the modulation pattern comprising a frequency pattern superimposed on the grid frequency;
5 and

decoding information encoded in the carrier signal on the basis of the determined correlation.

9. A method according to claim 8, wherein the testing device comprises a
10 data store storing one or more identifiers, and said modulation pattern includes an identifier of a testing device or group of devices to which the testing device belongs, the method comprising:

determining whether the identifier included in the modulation pattern corresponds to one or more of the one or more identifiers stored in the data store; and
15 processing the received signal on the basis of the determination.

10. A method according to either of claim 8 and claim 9, wherein said decoding comprises extracting data from the signal in response to determining that the identifier included in the signal corresponds to one or more of the one or more
20 identifiers stored in the data store.

11. A method according to any of claim 8 to claim 10, comprising:
monitoring, at the testing device, a number of cycles of the electric power flow in the grid that have elapsed from a given start point; and
25 determining timing information for the correlation process on the basis of said monitoring.

12. A method according to claim 11, comprising:
performing the correlation process according to a predetermined schedule, said
30 schedule identifying a timing for the performance of the correlation process on the basis of a number of cycles of the electric power flow that have elapsed from a given start point.

13. A method according to any of claim 6 to claim 12, wherein the correlation process comprises a correlating a time-base of the modulation pattern with a time-base of the one or more predetermined code patterns.

5

14. A method according to any of claim 6 to claim 13, wherein the correlation process comprises correlating a bit pattern of the modulation pattern with a bit pattern of the one or more predetermined code patterns.

10

15. A method according to any of claim 8 to claim 11, comprising:
identifying synchronisation data from the correlation process;
determining a start time on the basis of the synchronisation data;
monitoring, at the testing device, a number of cycles of the electric power flow in the grid that have elapsed with from the determined start time; and
15 extracting payload data encoded in the carrier signal after a predetermined number of cycles have elapsed from the determined start time.

20

16. A method according to any of the preceding claims, comprising performing a statistical analysis of data received from a plurality of testing devices to
20 determine a quality characteristic of the broadcast channel.

25

17. A method according to any of the preceding claims, comprising determining a local measure of the broadcast channel quality on the basis of a location of the testing device.

30

18. A method according to any of the preceding claims, wherein the second channel comprises one or more of: a cellular network; a wireless local area network; a wired local area network; a wide area network; a wired telecommunications network; and the internet.

19. A testing device for testing a broadcast channel, the broadcast channel being one in which information is transmitted within a synchronous area of an electric

power grid in which electric current flows according to a grid frequency, the information being transmitted based on instructions from a control node by modulating the grid frequency to provide a carrier signal having the information encoded therein, the testing device comprising:

5 a measuring means arranged to measure a characteristic relating to a frequency of power flowing in the electric power grid;

 a processing means arranged to extract a signal from the electric power grid based on said measured characteristic, the signal being based on a frequency modulation of the grid frequency; and

10 a communications interface arranged to send data indicative of a characteristic of the signal for receipt at the control node via a second channel different to the broadcast channel.

20. A testing device according to claim 19, wherein the processing means is
15 arranged to:

 evaluate the extracted signal with reference to data received via the second channel and stored at the testing device to determine a quality characteristic of the broadcast channel; and

 send data indicative of the determined quality characteristic for receipt at the
20 control node.

21. A testing device according to claim 20, wherein the processing means is arranged to perform one or more of:

 determine a signal-to-noise ratio of the extracted signal on the basis of the
25 extracted signal and the data received via the second channel;

 detect bit errors within the extracted signal on the basis of the extracted signal and the data received via the second channel;

 identify error coding data encoded within the signal and to perform an error checking process using the error coding data; and

30 identify interference in the channel on the basis of the extracted signal and the data received via the second channel.

22. A testing device according to claim 21, wherein the error checking process comprises a cyclic redundancy check.

23. A testing device according to claim 21 or claim 22, the processor is
5 arranged to assign a confidence value to respective bit values of the extracted signal.

24. A testing device according to any of claim 19 to claim 23, wherein the second channel comprises one or more of: a cellular network; a wireless local area network; a wired local area network; a wide area network; a wired telecommunications
10 network; and the internet.

25. A broadcast system comprising:
a transmitter arranged to transmit a frequency modulated signal via a broadcast channel within a synchronous area of an electric power grid;
15 a testing device according to any of claim 19 to claim 24; and
a control node arranged to communicate with the testing device via the second channel.

26. A broadcast system according to claim 25, wherein the control node is
20 arranged to provide transmission commands to the transmitter.

27. A broadcast system according to claim 25 or claim 26, wherein the control node is arranged to send, to the testing device, data indicative of a signal to be transmitted via the broadcast channel, the data being sent via the second channel.
25

28. A broadcast system according to any of claim 25 to claim 27, wherein the testing device is arranged to send, via the second channel, data indicating a quality characteristic of the broadcast channel, the data being for receipt at the control node, wherein the control node is arranged to initiate a change of one or more characteristics
30 of transmission from the transmitter on the basis of the quality characteristic.

29. A broadcast system according to claim 28, wherein the one or more characteristics of transmission comprises one or more of:

a forward error correction redundancy of a transmitted signal;

a signal strength of a transmitted signal;

5 a characteristic relating to length of a transmitted signal;

information encoded in a transmitted signal;

a bit coding length of a transmitted signal;

a characteristic relating to length of a cyclic redundancy check of a transmitted signal; and

10 power flowing to and/or from one or more transmitters.

30. A broadcast system according to any of claim 25 to claim 29, wherein the control node is arranged to initiate retransmission via the broadcast channel in response to a determination that the quality characteristic has a value below a
15 predetermined threshold value.

31. A broadcast system according to claim 30, wherein the control node is arranged to resend the transmission via the broadcast channel in response to a determination that the quality characteristic has a value below a predetermined
20 threshold value.

32. A broadcast system according to any of claim 25 to claim 31, comprising a plurality of distributed testing devices, wherein the control node is arranged to receive data indicating channel quality from the plurality of testing devices.
25

33. A broadcast system according to claim 32, wherein the control node is arranged to perform a statistical analysis of the data received from the plurality of testing devices to determine a quality characteristic of the broadcast channel.

30 34. A broadcast system according to claim 32 or claim 33, wherein the control node is arranged to determine a local measure of the broadcast channel quality on the basis of a location of the testing device.