power grid, the instructions including data indicative of a control function representing characteristics of a contribution to the one or more electricity characteristics to be made by the distributed plurality of power units during a control period;

retrieving, from a data store, profile information indicating one or more characteristics of a contribution that the first power unit is available to make during the control period;

determining, at the first power unit, based on the control function and the profile information, a first power unit contribution to the one or more electricity characteristics to be made by the first power unit during the control period; and

controlling power consumption from and/or provision to the electric power grid in accordance with the first power unit contribution.

In accordance with a second aspect of the invention, there is provided a computer program comprising instructions to perform, on a computerised device, a method according to the first aspect.

In accordance with a third aspect of the invention, there is provided a control device to control a power unit to perform a method according to the first aspect.

In accordance with a fourth aspect of the invention, there is provided a method for controlling one or more real or reactive electricity characteristics of electricity flowing in an electric power grid, the electric power grid being connected to a distributed plurality of power units each arranged to consume electric power from and/or provide electric real or reactive power to the electric power grid, the method comprising:

determining, at a control system, a contribution to be made to one or more electricity characteristics by a plurality of power units each arranged to consume electric power from and/or provide electric real or reactive power to the electric power grid during a control period;

selecting, at the control system, a first plurality of the distributed plurality of power units based on the determined contribution and profile information

control function at the given time instance, meaning that the sum contribution from a plurality of such power units 208 also follows, at least approximately, the shape of the control function. This method does not require any sophisticated control mechanisms at the power unit 208; it can be implemented using a simple on/off mechanism, as described above.

The fact that the power units 208 provide their contribution over a finite time span means that the shape of the collective response may "spread", resulting in a shape of contribution which deviates from the desired shape. For example, Figure 11 illustrates an example in which the desired contribution is a square wave; in this case, the finite length of the energy contribution from the selected power units 208 produces a contribution having sloped rather than vertical sides.

This may be addressed by the following approach. Instead of determining a time t_R based on the technique described above, the power unit 208 divides the control period into a number of discrete intervals $I_1 \ldots I_6$. Figure 12a illustrates an example in which a power unit 208 receives a control function indicating a control period of length T. The power unit 208 divides the control period T into intervals of length T_0, which may be equal to the length of time for which the power unit 208 is available to contribute. In the present example, T is not an exact multiple of T_0, so one period is included having a length T_1, less than T_0. Although, in the present example, the power unit 208 has selected the final interval I_6 to have the reduced length T_1, the interval having reduced length T_1could be included at any point in the sequence of intervals.

Having divided the control period into separate intervals $I_1 \ldots I_6$, the power unit 208 selects one of the intervals at random, and provides a contribution during the selected interval. In the case of the interval I_6 having reduced length T_1 being selected, if the power unit 208 is able to reduce the length of its contribution, it may do so such that the time length of the contribution is reduced to T_1.

This method enables a plurality of power units 208 to collectively provide a square shaped energy contribution to the electricity distribution grid 102. Given a sufficiently large number of power units 208, the desired shape of contribution is provided by the combined contribution of the power units 208.

On receipt of a control function representing a desired square-shaped contribution, a power unit 208 may divide the control period into intervals according to its characteristics, such as a length of time the power unit 208 is available to contribute. The control node 202 is not required to have any particular data regarding these characteristics; the determination of the length of the intervals is performed by the power units 208 individually.

This method of dividing the control period into discrete intervals may be particularly suitable when the length of the control period is several multiples of the time period for which the power unit 208 is available to provide a contribution. A given power unit 208 may therefore select whether to use this latter method, or the method described above with reference to Figure 10 based on the length of the control period relative to the length of the available contribution. For example, there may be a threshold value for the length of control period divided by the length of available contribution above which the method described with reference to Figure 12a is used.

Where the shape of the desired contribution is not square, and cannot be approximated by same, the desired shape can be provided (or approximated) by dividing the desired contribution into multiple contributions, and representing each by a different control function, each of which is provided to a different group of power units 208.

An example is illustrated in Figure 12ba, in which the contribution shown in the left hand graph is divided into the three separate contributions shown on the right hand side. Each of the three contributions is represented by a separate control function and sent to separate groups of power units 208, selected by the control node 202. The combined contribution from the separate groups sums to the desired contribution shown in the left hand graph (or an approximation thereof).

In cases where the desired shape of the contribution cannot be easily formed from square-shaped groups, the control node 202 may "flatten" the shape so as to provide an approximation of the desired shape.

consumed; state 2 in which the power unit 208 consumes power at 50% of its maximum power consumption; and state 3 in which the power unit 208 consumes power at 100% of its maximum power consumption. We assume that the value of the control function at a given time indicates that the power unit 208 should produce power at 75% of its maximum power consumption. In this case, this could be achieved by operating 50% of the time in state 2 and 50% of the time in state 3. Alternatively, it could be achieved by operating 25% of the time in state 1, and 75% of the time in state 3. Further alternatives using all three operating states are also possible, such for example, 10% of the time in state 1, 30% of the time in state 2 and 60% of the time in state 3. Any suitable combination of states may be used in embodiments of the present invention.

The start time of the PWM control may be randomised in order to prevent multiple power units 208 modulating in synchrony, which may produce undesirable variation in the power consumption/provision balance in the distribution grid 102. The randomisation may be implemented by, for example, generating a random number between 0 and 1, and, on the basis of the number generated, selecting a start time within a predefined start interval (e.g. 1ms).

In this further example, each power unit 208 provides a time-varying contribution in proportion to a value of the control function. The collective contribution from multiple power units 208 thus sums to a contribution having substantially the desired shape and magnitude of contribution as determined by the control node 202. A given power unit 208 contributing using the PWM method may contribute for the whole of the control period or for a proportion thereof, with different devices contributing at different times.

It should be noted that, for any group of power units 208 selected by the control node 202, different power units 208 of the group may use different methods to control their contribution. For example, one or more power units 208 of the group may provide a contribution using a method as described with reference to figures 10, one or more may use a method as described with reference to figure 1~~1~~2a and/or different ones of the one or more power units 208 may use the

a) Power units 208 which are unable to modify the duration of their contribution;

b) Power units 208 which are able to alter the duration of their contribution, but cannot modify their instantaneous power (e.g. simple on/off devices);

c) Power units 208 which are able to modify their instantaneous power.

Power units 208 of type a) and b) may use the methods described above with reference to figures 10 and 11-12a. In cases where the available time length of contribution of a power unit 208 is a high proportion of the length of the control period, in some cases it may be omitted from selection to avoid distortion of the profile shape. However, in some cases, for example where a degree of distortion is acceptable, such power units 208 may be included, and use the method described with reference to Figure 10. Power units 208 of type c) may use the further method described above, as exemplified by the PWM method.

Figure 13 shows an example of a control function having a total time length of T, and including a peak 1200 having a characteristic time length T_p For power units 208, of type a) and b), the control function may be sub-divided as described above with reference to Figure 12b.

Power units 208 of type b) may limit the length of time over which they contribute, in order to use the method described with reference to Figure 11-12a, so that they only contribute over a relatively small proportion of the control period.

For power units 208 of type c), in which the rate of contribution is controlled in proportion to the value of the control function, if the peak to average value of the control function is high, the power units 208 may be prevented from providing their full available contribution over the control period T.

Therefore power units 208 of both type b) and type c) may, in this scenario, contribute less than the total available contribution during the control period T. The control node 202, may take this into account when selecting power units 208. For example, the control node 202 may run a simulation of the contributions performed by available power units 208, taking into account operating characteristics such as the type of the power unit 208 (e.g. a), b) or c))

and/or an available duration of contribution, and select a combination of power units 208 able to provide both the desired total contribution and also the desired shape.

Using the methods described above, based on a control function representing a contribution to an electricity characteristic to be made by a group of power units 208, individual power units 208 determine characteristics of their individual contribution, based on profile information and the control function. This results in a collective contribution substantially according to the overall contribution represented by the control function. Since characteristics of the individual contributions are determined by the individual power units 208 themselves, the control node 202 is relieved from the burden concomitant with coordinating characteristics of the contribution from the individual power units 208. Further, because the same control function is broadcast to groups of power units 208, there is less burden on transmission resources compared to the case of sending individual instructions to individual power units 208.

Further saving on resources can be made according to a method as is now described.

The previous examples of a control function shown in figures 9, ~~11a~~, 12a11b, 12b and 13~~11c~~ comprise time-domain representations of a contribution. In some embodiments of the present invention the instructions sent from the control node 202 to the power units 208 may include a frequency-domain representation of the contribution. The control node 202 may perform a transform process to transform the time-domain representation into a frequency-domain representation. The transform process may comprise, for example, a Fourier transform or a wavelet transform. On receipt of instructions including the frequency-domain representation, a power unit 208 then performs a further transform process to transform the frequency-domain representation into a time-domain representation.

Transforming the time-domain representation into a frequency-domain representation may reduce the number of parameters that are required to define the control function. In order to define a time-domain representation, multiple

parameters may be required, such as rise and fall times, start and stop times, values of the control function at different time instances, and so on. Particularly for complex control functions, the number of parameters required may be very large, placing a burden on the connection between the control node 202 and the power units 208.

Transforming to a frequency-domain representation allows the number of parameters used to define the control function to be reduced. The frequency-domain representation may comprise, for example a series of complex numbers, as in the case for a Fourier series. The number of terms in the series may be limited according to quality requirements, for example.

Figure 134 shows an example of a target control function, along with the result of a transform to a time-domain representation at a power unit 208 of 5^{th} and 7^{th} order Fourier series frequency domain representations. It can be seen that the 7^{th} order representation deviates less from the target control function than the 5^{th} order representation. However, the 7^{th} order representation requires more parameters than the 5^{th} order representation, and therefore places a greater burden on the connection between the control node 202 and the power units 208. Accordingly the order of the representation may be varied in accordance with the quality of control function that is required.

The above example relates to Fourier transforms. However, it will be understood that other types of transform may be used, including other time-frequency transformations such as for example orthogonal and integral wavelet transforms which contain information similar to Fourier-transformations, but with the additional special properties of wavelets, which enable greater resolution in time at higher analysis frequencies of the basis function.

The methods of delivering control functions using a frequency-domain representation as described above, may be applied to other types of scheduling. For example, it may be used in situations in which the control node 202 specifies to each individual device the timings and/or other characteristics of its contribution, rather than delegating this to the individual devices according to the above methods.

electric power from and/or provide electric real or reactive power to the electric power grid during a control period;

selecting, at the control system, a first plurality of the distributed plurality of power units based on the determined contribution and profile information relating to the first plurality of power units, the profile information including information relating to one or more operating characteristics of the power units;

generating, at the control system, a control function providing a representation of characteristics of the determined contribution; and

sending, via a communication means of the control system, instructions to the first plurality of power units to control power consumption and/or provision, the instructions including an indication of the control function.

17. A method according to claim 16, wherein the determined contribution is a time-varying contribution.

18. A method according to either of claim 16 and claim 17, wherein the determining the contribution comprises dividing a desired contribution into a plurality of contributions, and the method comprises selecting a different plurality of the distributed plurality of power units for each of the plurality of contributions.

19. A method according to any of claim 16 to claim 18, wherein:

the determination of the contribution comprises determining a time-domain representation of the contribution; and

the generation of the control function comprises performing a transform process to generate a frequency-domain representation, such that the instructions comprise a frequency-domain representation of the control function.

20. A method according to claim ~~21~~19, wherein the transform process is performed on the basis of a precision requirement such that at least one characteristic of the frequency-domain representation varies according to the quality requirement.

21. A method according to either of claim 19 and claim 20, wherein the transform process comprises at least one of a Fourier transform or a wavelet transform or a similar time-frequency domain transform.

22. A method according to any of claim 16 to claim 21, wherein the one or more electricity characteristics comprises an energy characteristic.

23. A method according to any of claim 16 to claim 22, wherein the profile information includes at least one of: an amount of energy to contribute during the control period; a power consumption or provision characteristic; a duration of availability to provide a contribution; and a method used by a given power unit to control its contribution.

24. A computer program comprising instructions to perform, on a computerised device, a method according to any of claim 16 to claim 23.

25. A control system arranged to perform a method according to any of claim 16 to claim 24.

26~~5~~. A control system for controlling one or more electricity characteristics of electricity flowing in an electric power grid, the electric power grid being connected to a distributed plurality of power units each arranged to consume electric power from and/or provide electric power to the electric power grid, the control system comprising:

a processing means; and

a communication means,

wherein the processing means is arranged to:

determine a contribution to be made to the one or more electricity characteristics by a plurality of power units each arranged to consume electric

power from and/or provide electric power to the electric power grid during a control period;

select a first plurality of the distributed plurality of power units based on the determined contribution and profile information relating to the first plurality of power units, the profile information including information relating to one or more operating characteristics of the power units;

generate a control function providing a representation of characteristics of the determined time-varying contribution; and

send, via the communication means, instructions to the first plurality of power units to control power consumption and/or provision, the instructions including an indication of the control function.

276. A method for controlling one or more characteristics of electricity flowing in an electric power grid, the electric power grid being connected to a distributed plurality of power units each arranged to consume electric power from and/or provide electric power to the electric power grid, the method comprising:

determining, at a control system, a time-varying contribution to be made to the one or more characteristics by a plurality of power units each arranged to consume electric power from and/or provide electric power to the electric power grid during a control period;

selecting, at the control system, a first plurality of the distributed plurality of power units based on the determined contribution and profile information relating to the first plurality of power units, the profile information including information relating to one or more operating characteristics of the power units;

sending, via a communication means of the control system, instructions to each of the first plurality of power units to control power consumption and/or provision during the control period,

wherein the instructions sent to a given one of the first plurality power units include a frequency-domain representation of a time-varying contribution to be made by the given power unit to the one or more characteristics.

287. A method according to claim 276, comprising:

determining a time-domain representation of the time-varying contribution to be made by the given power unit; and

performing a transform process to transform the time-domain representation into the frequency-domain representation.