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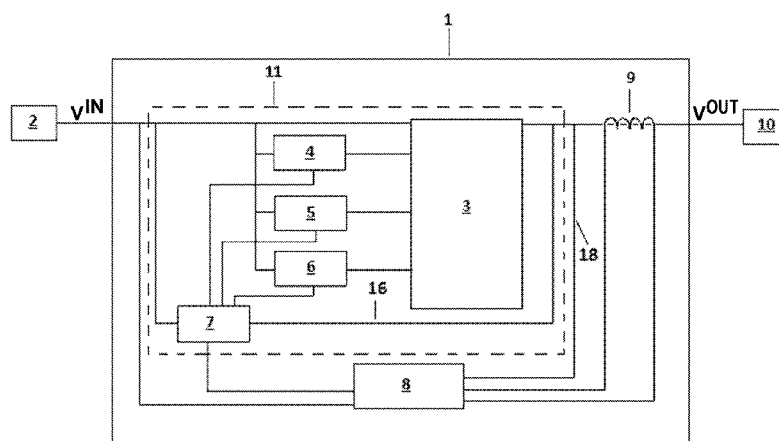


Figure 1

(57) Abstract: A voltage regulator arranged to control an output voltage to a load, has a voltage regulation means arranged to adjust an output voltage from the voltage regulator in response to a control signal, and an energy measurement means arranged to measure the power output from the voltage regulator. The energy measurement means is arranged to output the said control signal at at least a first and at a second level and to measure the power output at each level. A benefit of the invention is that a power consumer is provided with a means to regulate the voltage output to a load, such as that typically connected to a wiring installation, within an acceptable voltage range, so as to optimise energy consumption by the load, and the power consumer may be provided with voltage and current values, and hence using the power factor of the load, the power output of the voltage regulator to the load, at two different output voltages.



Improvements in and relating to power regulation devices

The present invention relates to voltage regulators arranged to control an output voltage to a load, and more particularly to voltage regulators arranged to adjust the output  
5 voltage from the voltage regulator in response to a control signal.

The regulation of voltage, and more particularly a general reduction in, the supplied mains voltage is known to generally provide a number of benefits, which may typically include a reduction in energy consumed by a load powered by such a regulated supply.  
10 Other benefits may include an increase in the life expectancy of electrical appliances and a reduction in carbon dioxide emissions. Devices which regulate voltage in order to achieve these benefits are known.

In order for a power consumer to be able to determine what effect a voltage regulation  
15 device is having on energy consumption, it is necessary to be able to accurately measure the difference in energy consumption at a site between the situations where the voltage is being regulated by such a device and where it is not. Furthermore, it is useful to a power consumer to be able to obtain further new energy consumption measurements following the installation of a voltage regulation device as the nature of the load at a site  
20 may change over time or at particular times.

However with known voltage regulation apparatus, it is very difficult to measure the energy saving that voltage optimisation provides. Generally this is done by comparing electricity usage over consecutive weeks using electrical distribution company meter  
25 readings. This method is inherently prone to errors as load levels and weather conditions change over such periods of time and therefore base load consumption may change from one measurement week to the next. Neither can this method allow a consumer to understand the effect of known changes in the load on the energy consumption.

30

It is an object of the present invention to provide a voltage regulator. This object can be achieved by the features as defined by the independent claim. Further enhancements are characterized by the dependent claims.

According to the present invention a voltage regulator arranged to control an output power to a load, comprises a voltage regulation means arranged to adjust an output voltage from the voltage regulator in response to a control signal, and an energy measurement means arranged to measure a power output from the voltage regulator, the  
5 energy measurement means being further arranged to output the said control signal at at least a first and at a second level and to measure the power output at each level.

A benefit of the invention is that a power consumer is provided with a means to regulate the voltage output to a load, such as that typically connected to a domestic or  
10 commercial wiring installation, within an acceptable voltage range, so as to optimise energy consumption by the load, and the power consumer may be provided with voltage and current values, and hence using the power factor of the load, the power output of the voltage regulator to the load, at two different output voltages may be measured.

15 Preferably at at least one of the control signal levels the output voltage is adjusted to be substantially the same as an input voltage to the voltage regulator.

A benefit of the output voltage being adjusted to be substantially the same as the input voltage is that the energy consumption of the load can be measured at the voltage it  
20 would be supplied with if the voltage regulator were not in the circuit, without having to electrically disconnect the voltage regulator from the circuit.

Preferably the output voltage is maintained within a maximum voltage and a minimum voltage.  
25

A benefit of having the maximum and minimum voltage range is that a stable output voltage can be provided where the input voltage may fluctuate over a greater range. A further benefit of the maximum and minimum voltage range is that this can be set to a narrower range than the acceptable range of voltage over which the load would be  
30 normally expected to function satisfactorily, and hence the performance of the load can be optimised.

Preferably the voltage regulation means is further arranged to adjust the output voltage to an optimum level where the output power is substantially at a minimum.  
35

A benefit of the output voltage being adjusted to the optimum level is that the cost of the energy used by the power consumer will be minimised.

5 Preferably the energy measurement means is further arranged to measure the power output by measuring the output voltage and output current at the first and at the second level at pre-determined intervals and or timed intervals, where the second level is preferably the said level at which the output voltage is substantially the same as the input voltage to the voltage regulator, and where the first level is the optimum level.

10 A benefit of measuring the power output at the different output voltages is that the power consumer may establish the savings made by operating the load at the optimised voltage.

15 Preferably the energy measurement means is further arranged to adjust the control signal to measure the power output at the first and at the second level at the request of a user.

20 A benefit of the measurement being made at the user request, is that the user can obtain current information quickly and without disrupting the connection of the load to the supply. A further benefit is that the power consumer is empowered to make informed decisions regarding the use of the voltage regulator and the load connected to it to further reduce their energy costs.

25 Preferably the energy measurement means is further arranged to measure an average of output power over a period of time and or the total energy used.

30 A benefit of measuring power and or energy used over a period of time is that the user may be provided with a clear indication of the current and or cumulative costs of operating the load. A further benefit is that the user may be provided with an indication of the cost savings arising from using the voltage regulator.

Preferably the energy measurement means is further arranged to monitor the output current while the control signal is at one level and when the current has changed by a significant amount, and preferably when the change has been maintained for a period of

time, the control signal is adjusted to the other level, and a measurement is made of voltage and current output from the voltage regulator.

5 A benefit of monitoring the output current is that an effect on the power usage of significant changes in the load can be quickly established, and the indication of cost savings updated accordingly.

Preferably the voltage regulation means comprises transforming apparatus, the transforming apparatus preferably further comprising an autotransformer.

10

A benefit of using an autotransformer is that the voltage regulation of the alternating current supply may be achieved with high efficiency, high reliability and low costs.

15 Preferably the energy measurement means further comprises an output means, the output means preferably comprising a memory storage means, the output means preferably further arranged to provide output in a user readable form.

20 A benefit of using a storage means is that the user may be provided with a historical analysis of the energy usage over an extended period of time. A further benefit is that the analysis may assist in identifying trends or periodic events which affect the costs incurred by the power consumer. A benefit of the historical analysis is that informed decisions may be taken to further reduce energy costs.

25 Preferably the output means further comprises a remote access means, the remote access means being preferably a wired or a wireless network connection means.

30 A benefit of remote access to the energy measurement means is that a user may monitor the costs of a particular installation from a remote location. A further benefit is that the user may in a suitably enabled installation remotely manage the load so as to further optimise the energy usage.

35 A benefit of the invention is that the voltage regulator provides the function of the automatic adjustment of the voltage supplied to a power consumer's site with the function of near real-time measurement and comparison of energy consumption levels across the site whilst the supplied voltage is adjusted and whilst it is not adjusted.

The voltage regulator is capable of measuring energy consumption by load devices across a power consumer site whilst the supplied voltage is adjusted and whilst it is not adjusted since it comprises a voltage regulation device adapted to adjust the output  
5 voltage, which is inter-connected to an energy measurement device adapted to both control the voltage regulation device and measure the power flowing to the load devices.

This involves voltage adjustment by the voltage regulation device to different output  
10 voltage states followed by the measurement of the power flowing to the load each such voltage state. Any large change in output voltage is preferably done gradually so as not to be noticeable to the power consumer but adjustments from one output voltage step to the next should be done at high speed in order to avoid interruption to the supply.

15 An example of a device capable of high speed voltage adjustment would comprise an autotransformer having a plurality of output taps, the taps arranged to provide a range of outputs between a maximum transforming ratio and a minimum transforming ratio, and switching apparatus arranged to connect a selected tap to a load, the switching tap being further arranged to connect a different tap to the load within a switching time of less  
20 than a thousandth of the time for one complete cycle of a 50 hertz supply. Preferably the switching apparatus is arranged to switch between taps at or close to a zero voltage crossing point of the voltage across the switch.

This invention has the advantages of enabling accurate measurement of energy  
25 consumption difference across a site in both the voltage regulated and unregulated states which is of importance to end-users as it enables the end-user to accurately know whether the voltage regulation device is leading to any energy saving and the extent of such energy saving. This enables end-users to know whether the voltage regulation device is beneficial to them and to quantify its utility. It provides them with the  
30 opportunity to be able to use the energy consumption figures to accurately demonstrate the amount of energy that they are saving by use of the device which is beneficial in the current regulatory, political and commercial environment's focus on energy consumption and more specifically carbon dioxide emissions. Particularly, end-users can use these figures to demonstrate compliance with carbon dioxide reduction  
35 commitments and as part of energy usage audits.

The information provided by the energy consumption analysis can be used to compile reports in which the reduction in the cost of the energy consumed by an end-user as a result of the use of the voltage regulation device is calculated and presented.

5 Furthermore, reports of the reduction in carbon dioxide emissions can also be compiled. This information could either be reported directly by the device on a display screen or remotely by way of uploading the necessary information to the internet and making that accessible to the end-user by a web interface.

10 Specific embodiments of this invention will now be described, by way of example only, with reference to the accompanying drawings in which:-

Fig. 1 is block circuit diagram of a first embodiment of a voltage regulator according to the present invention for regulating a single phase power supply comprising a voltage  
15 regulation means and energy measurement means;

Fig. 2 is a block circuit diagram of a second embodiment of voltage regulator according to the present invention comprised of a voltage regulation means and a separate energy measurement means;

20

Fig. 3 is a diagrammatic graph of output voltage of the voltage regulation means on the instruction of the energy consumption measurement unit from target output voltage to a voltage equal to that of the mains supply voltage and back to the target output voltage where the target output voltage is less than the mains supply voltage;

25

Fig. 4 graphically demonstrates the change in load power consumption during the output voltage adjustment shown in Fig. 3; and

Fig. 5 is a diagrammatic graph of a change in control signal levels output by the energy  
30 measurement means that initiates the output voltage adjustment shown in Fig. 3, the graphs in Figures 3, 4 and 5 all share the same common Time axis.

From Figure 1 a voltage regulator 1 according to the present invention is shown interposed between single-phase power mains input 2 at a supply input voltage  $V^{IN}$  and  
35 the output 10 at a regulated output voltage  $V^{OUT}$  which is an input to a power consumer

facility 10. A voltage regulation device 11 is a voltage regulation means and is connected between the mains input and the facility input. The voltage regulation device comprises an autotransformer 3 with tap changing on the output of the transformer. Such a transformer would have a number of taps to it to give it an accurate output  
5 voltage for a wide range of input voltage. The taps are switched by generously rated electronic switches such as TRIACs, of which three are represented by switches 4, 5, 6, to connect selected taps to the output side of the transformer windings. The electronic switches are controlled by an electronic controller 7 to determine which taps are to be connected. This electronic controller 7 is connected 16 to the output of the  
10 autotransformer 3 in order to be able to monitor the output voltage so that the output voltage can be maintained at a desired level. Each tap represents a different voltage that is either a step up or step down from the mains supply voltage and the tap that is selected will determine the output voltage supplied to the facility load devices. One such tap will provide the same voltage  $V^{\text{OUT}}$  on the output at 10, as at the supply  $V^{\text{IN}}$  on  
15 the input 2.

An energy measurement device 8 is an energy measurement means and has a microcontroller in electrical communication with the voltage regulation device electronic controller 7. The energy measurement device is further connected to the  
20 output of the autotransformer and current sensor 9 in order that the voltage  $V^{\text{OUT}}$  at 18 and current being supplied to the load devices 10 may be measured. A power measurement is made by measuring the output voltage and output current and the power factor at which the load is operating. The energy measurement device 8 is represented in Fig. 1 as being a separate component from the voltage regulation device electronic  
25 controller 7 but it is recognised that in an alternative embodiment they may be combined in the same component.

In the context of a three-phase alternating current mains supply, the voltage regulation device represented in Fig. 1 would comprise three single-phase voltage regulators in  
30 order to regulate the voltage of each of the three phases individually. These three voltage regulators would then be connected together as is known already to enable full three-phase control.

A second embodiment of the voltage regulator 17 according to the invention, is shown  
35 in Fig. 2, differs from that in Fig. 1 by way of the energy measurement means, energy

measurement device 12, being in a separate unit from the voltage regulation means, voltage regulation device 15. Features closely similar to those shown and described with reference to Figure 1 have been numbered identically to Figure 1. The remote energy measurement device is connected to the voltage regulation device electronic controller 7 by way of connection 13 in order that control signals may be passed from the energy measurement device to the voltage regulation device electronic controller. This remote energy measurement device 12 is connected to a remote current sensor 14 which is connected to the output of the voltage regulator to measure the current being supplied to the load devices. The energy measurement device 12 is also connected at 19 to the output of the voltage regulator for the purpose of measuring the output voltage  $V^{OUT}$ .

The energy measurement device in either embodiment is a microcontroller capable of electronically controlling the voltage regulation device for the purpose of adjusting the output voltage in order to enable energy consumption measurements at different output voltage states. The control of the voltage regulation device is achieved by communicating control signals to the voltage regulation device electronic controller. The energy measurement device is also programmed to measure the power flowing to the load devices.

20

Fig. 3 provides a graphical representation of an example adjustment of the output voltage for the purpose of energy consumption measurements during the normal operation of the voltage regulation device. The example is provided in the context of the voltage regulation device having a target output voltage that is less than the mains input voltage. This is typically the situation encountered, since a power supply authority will tend to maintain the supply voltage at a level between a statutory maximum and minimum supply voltage. When this is the case, the target output voltage, which would normally be an optimum operational voltage for minimising energy costs for a power user, will typically be substantially at or close to the statutory minimum voltage.

30

While the electronic controller within the energy measurement device 8 or 12 is providing an output signal 40 at a first signal level L1 (shown in Figure 5) to the voltage regulation means 11 or 15 via connection 13, energy measurement means is arranged to

measure power consumption at the target output voltage  $V^{OPT}$  represented at point 20 on the graph.

Subsequently at time T0 (Figure 5) the energy measurement device would change the  
5 output signal level to 41 which is a second signal level L2, and hence the energy  
measurement device instructs the control module within the voltage regulation device to  
switch up through the transformer taps sequentially, which is the process represented at  
23, until the voltage regulation device output voltage  $V^{SV}$  is equal to the mains supply  
voltage  $V^{IN}$  which is represented at point 21 on the graph of Figure 3. It should be  
10 noted that the response of the load 10 to the change in output voltage  $V^{OUT}$  may not be  
linear, which is indicated by curve 33 in Figure 4. Since the voltage regulation means  
11 or 15, is arranged to make the voltage adjustment over a period of time T1 so as to  
cause minimum disturbance in the load 10, the signal level change may conveniently be  
a step change 43.

15

Once a stable output voltage at 21 and a steady power consumption at 31 is reached, a  
power measurement would be recorded at this point 21 as before. The control module 7  
within the voltage regulation device 11 or 15 would then be instructed by change 44 in  
the signal level 42 back to level L1, to switch down through the transformer taps  
20 sequentially, which is the process represented at 24, until the output voltage  $V^{OUT}$   
reaches the target voltage  $V^{OPT}$  again represented at point 22 on the graph. It should be  
noted that the power taken by the load 10 will reduce as represented by non-linear curve  
34. In this example model the power controller device measures the power supplied to  
the facility load devices at the target output voltage and at an output voltage equal to the  
25 mains supply voltage to enable the comparison of energy consumption measurements  
between a state in which the output voltage is regulated and a voltage that would be  
supplied if it were not regulated at all. However, this same process may be used to  
obtain power measurements at different output voltage states between the target output  
voltage and the mains supply voltage and irrespective of whether the target output  
30 voltage is higher or lower than the mains supply voltage.

To ensure that reliable measurements are made, the energy measurement device 8, 12 is  
preferably arranged to monitor the output voltage and the load power consumption just  
prior to taking a reading of power consumption and while taking the reading, to ensure  
35 that the load is operating in a stable condition, that is prior to T0 and during period T2.

Further, the energy measurement device 8, 12 is preferably arranged to verify that the load characteristics have not changed while the readings were being taken, by taking a confirmatory reading after the expiry of the time period T3 when the output voltage has returned to the target voltage  $V^{\text{OPT}}$  and the load power consumption is again steady at 5 32.

The energy measurement means may establish that the output voltage is equal to the mains supply voltage by making a separate measurement of the input voltage. 10 Alternatively, the voltage regulation means may be arranged so that the auto-transformer can be switched to provide a 1:1 transformer ratio between the input and the output, or such ratio as is required to compensate for losses in the transformer.

In a typical installation where there is minimal user input, the energy measurement 15 means is arranged to poll the output power to establish the energy consumption in the optimised versus the non-optimised (that is at the supply voltage) according to a regular timed schedule. In a typical installation this would be at approximately weekly intervals, although the intervals could be much longer, say a year or for particular installations where the load was predictable, up to say once every three years. Since the 20 complete cycle for a typical measurement will take say, 25 seconds, where time period T1 and T3 would be approximately 10 seconds and time period T2 would be approximately 5 seconds, in an average installation, a shortest time interval would be approximately every 30 seconds. However, at this frequency, as can be seen from Figures 3 and 4, the act of measuring the power saving would significantly impact on 25 the saving itself.

Where the load is known to change cyclically over time, such as a lighting load varies with the time of day, in such an application, the polling interval preferably has a randomised element so that consecutive measurements are taken at different points in 30 the load's cycle.

As indicated in Fig. 3 the output voltage is preferably stepped up gradually from the target voltage 20 to the point 21 at which the output voltage is equal to the mains supply voltage, typically over a period of time of approximately ten seconds in order to avoid 35 the change in voltage being noticeable at the site. The output voltage is preferably

maintained at point 21 for period T2 which is typically approximately 5 seconds while the load power consumption is measured. The output voltage is then stepped down gradually again, typically over a period of approximately ten seconds to point 22.

- 5 In particular installations, it may be necessary to use a longer interval T1 and T3 when ramping the output voltage up or down, such an interval being approximately 5 minutes long in each case.

For installations where the effect of faster voltage changes is acceptable, the interval  
10 when ramping the output voltage up T1 and down T3 may be much less, and the length of time required will depend on the magnitude of the voltage change between the target voltage 20 and the supply voltage equivalent 21.

In a particular embodiment, a minimum period T2 for which the output voltage is  
15 maintained at point 21 while load power is measured is one complete cycle of the output voltage.

In a particular embodiment of the voltage regulator according to the present invention, closely similar to that shown and described above with reference to Figures 1 and 2, the  
20 energy measurement means 8, 12 is arranged to monitor the output current at 9, 14 while the control signal is at one level L1, 40, 42 (Figure 5) and when the current has changed by a significant amount, and preferably when the change has been maintained for a period of time, the control signal is adjusted to the other level L2, 41, and a measurement is made of voltage at 18, 19 and current at 9, 14 output from the voltage  
25 regulator 1, 17. A change in current that would be significant will depend in part on the total load current, since for a small installation of, say a total maximum load of 15kW, a change of 0.1kW to 0.5kW could be considered significant, while for a larger installation, a change of say, 3kW might be more appropriate. Likewise, a relevant period of time will be dependent on how frequently loads are switched, and how  
30 frequently power measurements are normally taken. Where frequent measurements are taken, a shorter time period may be more appropriate. Since the complete cycle for a typical measurement will take say, 25 seconds in an average installation, a typical installation where measurements are scheduled to be made weekly, a suitable time for a said period would be an hour.

35

A benefit of measuring the power savings when the load changes is that a significant change in load may indicate a change in the type of load connected, and hence the actual power saving between operating at the optimised voltage and the supply voltage may change significantly. Hence, by taking a measurement when the load changes  
5 significantly, the accuracy of the estimated savings is greatly improved.

The power measurements and other variables recorded by the electronic controller in taking these measurements such as output voltage, current and power factor may be presented to an end-user by one or more well known methods for presenting electronic  
10 data visually, such as presentation of the data on a liquid crystal display. The data may also be stored on a memory storage device so that it can be downloaded onto a personal computer for further analysis. Suitable memory storage devices would include solid state memory, and in particular non-volatile memory devices. Furthermore, the energy measurement device may be provided with connectivity to the internet by wired or  
15 wireless connection in order that this electronic data may be uploaded to a remote internet computer server.

In use, a user arranges for the voltage regulator 1, 17 to be connected between the mains electrical supply 2 and the user's local distribution circuits 10 in their premises which  
20 are to be supplied with power 30, 31, 32 (Figure 4). The voltage regulation means 11, 15, which comprises a means for providing an output voltage at a different value to the input voltage, is arranged to adjust an output voltage  $V^{OUT}$  from the voltage regulator to an optimum voltage  $V^{OPT}$  so as to obtain benefits of close control of output voltage and a reduction in operating costs of the load 10. The voltage regulation means preferably  
25 has internal feedback means to ensure that the output voltage is maintained over a wide range of output current values. The voltage regulation means 11, 15 is also arranged to change the output voltage  $V^{OUT}$  in response to a control signal 40, 41, 42 (Figure 5) from an energy measurement means 8, 12. The energy measurement means is arranged to measure a power output 30, 31 and 32 from the voltage regulator to the load, by  
30 measuring voltage 18, 19 and current using current transformer 9, 14 and power factor at stable voltages 20, 21, 22 respectively corresponding to the control signals 40, 41, and 42 respectively.

The embodiments of the invention discussed above enable the user, a power consumer,  
35 to conveniently and safely monitor the cost savings arising from the use of the voltage

regulator without having to manually disconnect and reconnect the electrical supply to the load and without having to manually set the operating conditions while monitoring.

5 The signal levels herein are required for control of the voltage regulation means, and that in a particular embodiment it is convenient to arrange for the voltage regulation means to default to the optimum voltage output when the signal level L1 is a zero or null value.

10 In a further particular embodiment, it is convenient for the voltage regulation means to default to the output voltage being substantially the same as the input voltage when the signal level L2 is a zero or null value.

15 While the invention has been particularly shown and described with reference to the preferred embodiment, it will be understood by those skilled in the art that the foregoing and other changes in form and details can be made without departing from the scope of the appended claims.

CLAIMS

1. A voltage regulator arranged to control an output power to a load, comprising  
5 a voltage regulation means arranged to adjust an output voltage from the voltage  
regulator in response to a control signal, and  
an energy measurement means arranged to measure a power output from the  
voltage regulator,  
the energy measurement means being further arranged to output the said control  
10 signal at at least  
a first and at a second level and  
to measure the power output at each level.
2. A voltage regulator as claimed in claim 1, wherein  
at at least one of the control signal levels  
15 the output voltage is adjusted to be substantially the same as  
an input voltage to the voltage regulator.
3. A voltage regulator as claimed in claim 1 or 2, wherein  
the voltage regulation means is further arranged  
20 to maintain the output voltage within  
a maximum voltage and a minimum voltage.
4. A voltage regulator as claimed in claim 3, wherein  
the voltage regulation means is further arranged to adjust the output voltage to an  
25 optimum level where  
output power is substantially at a minimum.
5. A voltage regulator as claimed in any of the preceding claims, wherein  
the energy measurement means is further arranged  
30 to measure the power output at the first and at the second level  
at timed intervals,  
and when dependent on claim 2, the second level being preferably being the said  
level at which the output voltage is substantially the same as the input  
voltage to the voltage regulator,  
35 and when dependent on claim 4 the first level being the optimum level.
6. A voltage regulator as claimed in any of the preceding claims, wherein  
the energy measurement means is further arranged to adjust the control signal

to measure the power output at the first and at the second level  
at the request of a user.

7. A voltage regulator as claimed in any of the preceding claims, wherein  
5 the energy measurement means is further arranged to measure  
an average of output power over an interval of time.
8. A voltage regulator as claimed in any of the preceding claims, wherein  
10 the energy measurement means is further arranged  
to monitor the output current while the control signal is at one level and when the  
current has changed by a significant amount, and preferably when the change  
has been maintained for a period of time,  
a measurement is made of the power output at that signal level, and then  
the control signal is adjusted to the other level, and a measurement is made of  
15 power output from the voltage regulator.
9. A voltage regulator as claimed in any of the preceding claims, wherein  
the voltage regulation means comprises transforming apparatus,  
the transforming apparatus preferably further comprising an autotransformer.  
20
10. A voltage regulator as claimed in any of the preceding claims, wherein  
the energy measurement means further comprises an output means,  
the output means preferably comprising a memory storage means,  
the output means preferably further arranged to provide output in a user readable  
25 form.
11. A voltage regulator as claimed in claim 10, wherein  
the output means further comprises a remote access means,  
the remote access means being preferably a wired or a wireless network  
30 connection means.
12. A voltage regulator arranged to control an output power to a load substantially as  
described with reference to any one or more of the accompanying drawings.

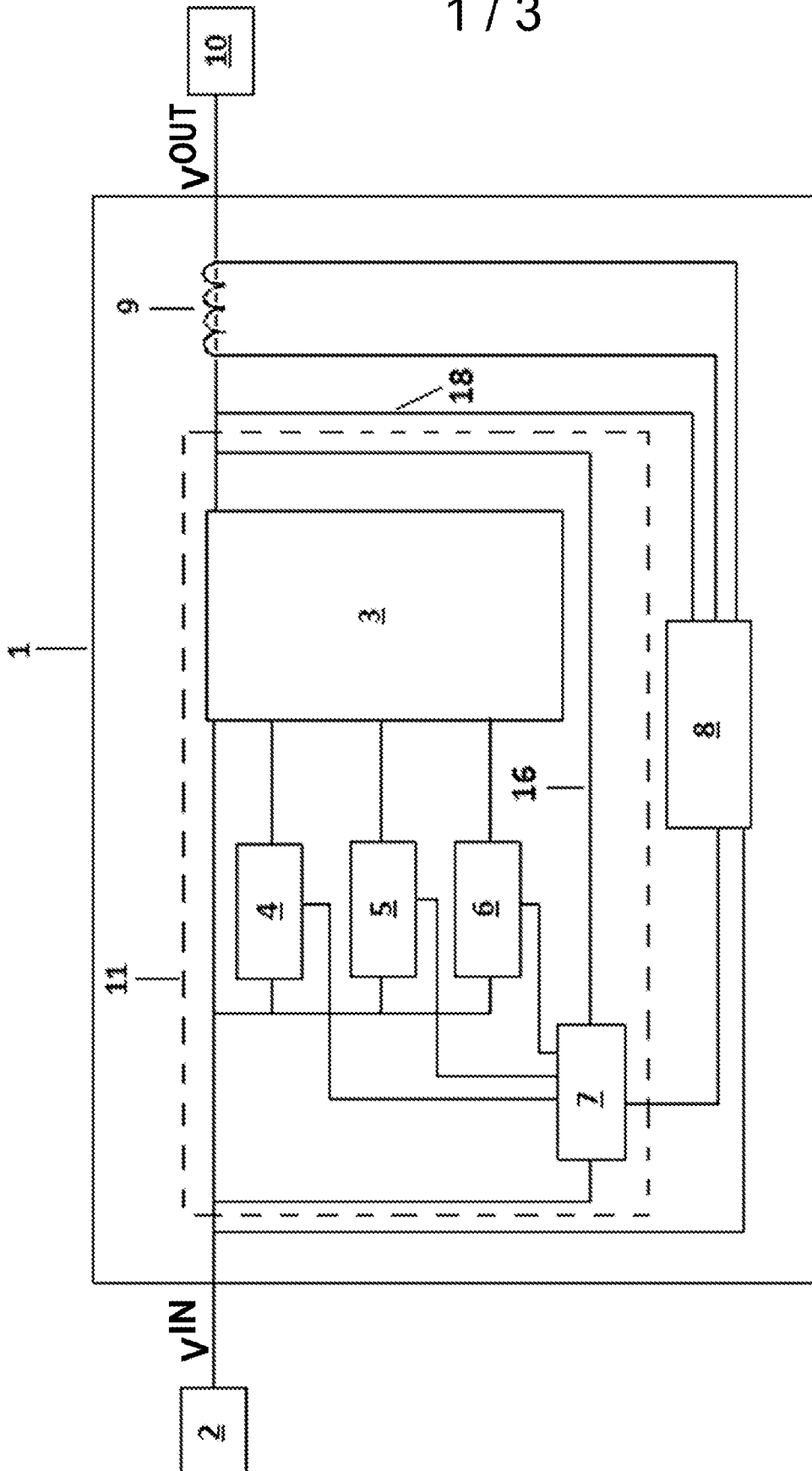


Figure 1

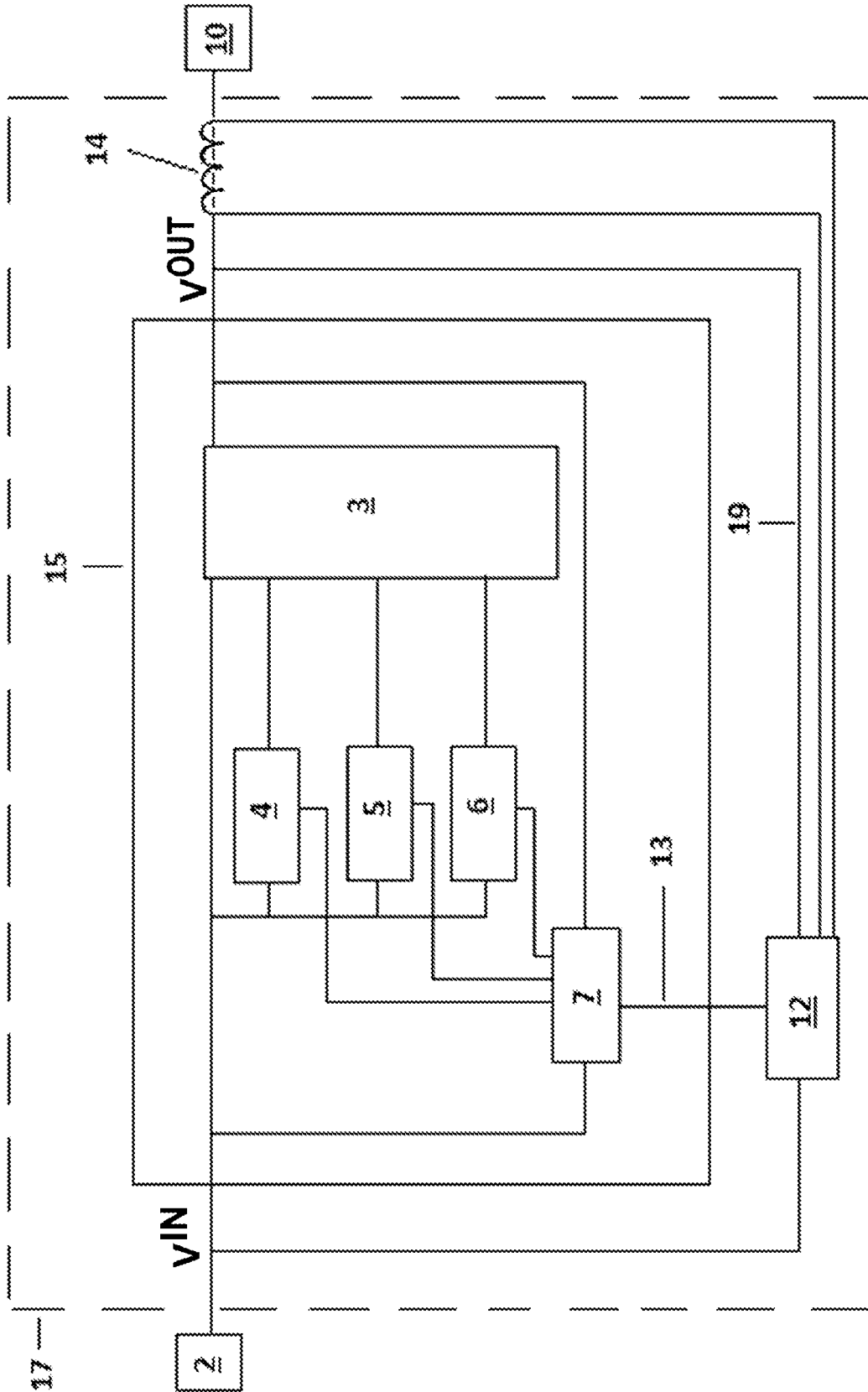


Figure 2

