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(54) **Title:** METHOD AND APPARATUS FOR ALLOCATING ELECTRICITY FROM A DISTRIBUTOR

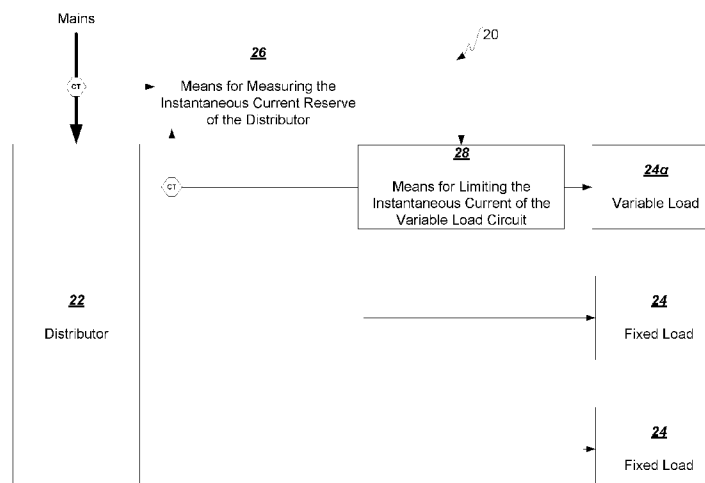


Figure 1

(57) **Abstract:** The present invention provides a method and apparatus for allocating current (20) from a distributor (22), having a maximum rated current, among a plurality of load circuits (24), including a variable load circuit (24_a) that benefits from a full load current allocation but is operable at a lower current allocation. The invention provides for measuring the instantaneous current reserve of the distributor (22) as the maximum rated current of the distributor (22) less the instantaneous current flowing from the distributor (22) to the plurality of load circuits (24), and limiting the instantaneous current of the variable load circuit (24_a) to the full load current of the variable load circuit (24_a), if the instantaneous current reserve is greater than zero, and the sum of the full load current of the variable load circuit (24_a) plus the instantaneous current reserve, if the instantaneous current reserve is less than or equal to zero.

METHOD AND APPARATUS FOR ALLOCATING ELECTRICITY FROM A DISTRIBUTOR

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

[0001] The present invention relates to allocating current from a distributor.

More particularly, the present invention relates to allocating current from a distributor having a maximum rated current capacity, among a plurality of load circuits, including a variable load circuit that benefits from a full load current allocation but is operable at a lower current

10 allocation, for example a charging circuit for an electric vehicle battery.

2. Description of the Related Art

[0002] Electrical distributors, for example distribution panels, are conventionally designed such that the aggregate current carrying capacity of all branch circuits is significantly higher than that of the main circuit breaker. In other words, the design assumes that not all branch circuits will supply loads -- let alone full loads -- simultaneously. Each branch breaker is limited to relatively small load capacities, a standard which is derived from statistical analysis of standard consumption patterns. Also worth noting is that the main panel breaker circuit is often characterized by periods of electrical current demand well below its maximum capacity.

20 **[0003]** When demand for current exceeds the capacity of the distributor, load-shedding is a commonly used method to ensure that the combined loads do not exceed the maximum rated current capacity, typically as established by the main breaker, but more generally established by the lowest capacity component in the main circuit. Through shedding, branch loads are selectively disconnected or disabled when this capacity is approached. This

method is used on common branch circuits with fixed or strictly limited variable loads. When the aggregate load of all branch circuits reaches the current capacity rating of the main breaker in the distribution panel, selected loads are switched completely off to reduce the total load on the system. There are no intermediary stages of such load-shedding; either a branch is on or it is off.

5 **[0004]** This arrangement is sufficient where the contemplated current load on each branch circuit is either fixed or varies within relatively narrow prescribed limits. However, when the current load in a branch circuit is highly variable, and might even rise above the capacity of the main breaker itself, a more flexible, robust and effective solution is necessary and provides the motivation for this invention.

10 **[0005]** A case in point is opportunity charging for batteries. Batteries can be charged at various rates. When spare capacity exists, there is an opportunity to charge batteries faster. When capacity is limited, charging can be reduced or postponed by shedding a variable amount of the load.

[0006] It is common for battery chargers to employ current-control circuitry, but
15 this circuitry is limited to battery-state sensing in order to maximize battery life and prevent damage, not to the sensing of available supply current. By enabling the charger to maximize the charge rate of sensitive batteries, the danger of the battery undergoing excessive deep-discharge cycles is minimized and battery life thereby extended.

[0007] As battery-powered electric vehicles become more common, better
20 opportunity charging arrangements will be needed to enable smaller household circuits, with their limited current capacity, to efficiently and effectively recharge vehicle batteries. Such arrangements would make larger charging currents available on demand -- when capacity is available -- in order to reduce the time it takes to charge a battery bank. As other demands are placed on the distributor, the battery charging load can be partially or completely shed.

25 **[0008]** Such opportunity charging arrangements would allow the use of a charger branch circuit with much higher current ratings than would normally be available. There are

many examples of current sensor technology applied to the measurement, display and shedding of current loads in both household and industrial settings, but none appear to apply the signals thus derived to the variable control of specific current loads in those environments.

5

SUMMARY OF THE INVENTION AND ADVANTAGES

[0009] In a large-scale electric vehicle battery employing 6000 Li-Ion cells where

the maximum charge current per cell can be 2.6A, the peak charge current demand could be as high as 15,600A at 4V or about 2600A at 240V. Such demands are unsupportable by typical

10 household main breaker ratings of either 100A or 200A. The optimum solution is to provide enabling technology that allows the transfer of any excess current capacity of the main breaker circuit to the battery charger branch circuit. Such an approach allows the installation of a branch circuit with a current carrying capacity of about 80% that of the main breaker circuit. During peak current demand times a current sensor signal would activate restraint of the charging
15 current to some safe value that does not incrementally exceed the rating of the main breaker, while during periods of lower aggregate demand it would allow it to increase to its maximum branch circuit rating.

[0010] What is needed is a charging arrangement that can supply a variable load

of a much higher current capacity rating than conventional branch circuits. A variable load-

20 shedding arrangement that permits variable current limiting of the high capacity branch circuit for, as the remaining conventional branch circuits draw more or less current as needed. As the current draw varies on the conventional branch circuits, the high capacity variable load circuit varies its current draw to prevent the entire circuit from exceeding the maximum main breaker current, and advantageously, to provide a much higher charging rate as opportunities arise.

25 **[0011]** This invention effectively makes it possible to design branch circuits with much higher current carrying capacity and to transfer any unused current capacity in the main

circuit to them, within their increased current carrying limits. It also provides enabling technology that permits the design of electric vehicle battery chargers that can avail themselves of this arrangement. The current load in the branch circuit may be an electric vehicle battery charger. This invention delivers enabling technology so that the charger is able to control its
5 current demand subject to available current capacity.

[0012] According to one aspect of the present invention, there is provided a method of allocating current from a distributor having a maximum rated current among a plurality of load circuits including a variable load circuit that benefits from a full load current allocation but is operable at a lower current allocation, comprising: (a) measuring the
10 instantaneous current reserve of the distributor as the maximum rated current of the distributor less the instantaneous current flowing from the distributor to the plurality of load circuits, (b) limiting the instantaneous current of the variable load circuit to: (i) the full load current of the variable load circuit, if the instantaneous current reserve is greater than zero, and (ii) the sum of the full load current of the variable load circuit plus the instantaneous current reserve, if the
15 instantaneous current reserve is less than or equal to zero.

[0013] This method of allocating current from a distributor might be applied to a distribution panel or even a distribution transformer.

[0014] In some cases, at least one aspect of measuring and limiting might be performed in an analog manner, for example representing respective currents as respective
20 voltages and comparing or summing the respective voltages.

[0015] More particularly, this could be accomplished by representing the maximum rated current of the distributor by setting a reference voltage, representing the instantaneous current flowing from the distributor to the plurality of load circuits by generating an instantaneous voltage signal in response to the instantaneous current, and measuring the
25 instantaneous current reserve of the distributor by summing the reference voltage and the instantaneous voltage signal.

[0016] Furthermore, one might represent the full load current of the variable load circuit by setting a second reference voltage, and limit the instantaneous current of the variable load circuit by first comparing the instantaneous current reserve to ground and then, if the instantaneous current reserve is greater than ground, limiting the instantaneous current of the variable load circuit to the full load current of the variable load circuit, and if the instantaneous current reserve is less than ground or equal to, limiting the instantaneous current of the variable load circuit to the sum of the full load current of the variable load circuit plus the instantaneous current reserve.

[0017] In some cases, at least one aspect of measuring and limiting might be performed in a digital manner, for example representing the respective currents as binary values and operating upon the binary values.

[0018] More particularly, this could be accomplished by representing the maximum rated current of the distributor by setting a memory register, representing the instantaneous current flowing from the distributor to the plurality of load circuits as the output of an analog to digital converter coupled to a current sensor, and measuring the instantaneous current reserve of the distributor by subtracting the instantaneous current flowing from the distributor from the maximum rated current of the distributor.

[0019] Furthermore, one might represent the full load current of the variable load circuit by setting a memory register and limit the instantaneous current of the variable load circuit by comparing the instantaneous current reserve to zero, and if the instantaneous current reserve is greater than, limiting the instantaneous current of the variable load circuit to the full load current of the variable load circuit whereas if the instantaneous current reserve is less than or equal to zero, limiting the instantaneous current of the variable load circuit to the sum of the full load current of the variable load circuit plus the instantaneous current reserve.

[0020] Limiting might include issuing a limit signal in response to the measured instantaneous current reserve circuit. The limit signal might be issued to a current limiter

coupled to the variable load or to a current limiter integrated with the variable load, perhaps wirelessly. The limit signal might be issued to a current limiter at the head of the variable load circuit or to a current limiter integrated with the distributor at the head of the variable load circuit. The limit signal might be pulse-width variable, perhaps in accordance with the SAE J1772 standard.

[0021] At least one of measuring and limiting might be responsive to a user-input signal, for example a user-input signal generated remote from the distributor.

[0022] At least one of measuring and limiting might be responsive to a safety signal, for example a safety signal that is feedback from the limit signal. The safety signal might be compliant with the SAE J1772 standard.

[0023] By extension, limiting the current of the variable load circuit could include limiting the respective currents of a plurality of variable load circuits, for example sharing the instantaneous current reserve such as by sharing an instantaneous reserve current from the distributor. This end might be accomplished through multiplexing the instantaneous reserve current.

[0024] Measuring the instantaneous current reserve of the distributor could include measuring the instantaneous current reserve of the distributor as the maximum rated current of the distributor less the instantaneous current flowing from the distributor in the phase corresponding to the phase of the variable load circuit.

[0025] In cases where the distributor is configured for at least one of split-phase and multi-phase supply and the variable load circuit is configured as a multi-phase load, measuring the instantaneous current reserve of the distributor might include measuring the instantaneous current reserve of the distributor as the maximum rated current of the distributor less the largest of the instantaneous currents flowing from the distributor in each of the multiple phases supplying the variable load.

[0026] An apparatus for allocating current from a distributor having a maximum rated current among a plurality of load circuits including a variable load circuit that benefits from a full load current allocation but is operable at a lower current allocation, comprising: (a) means for measuring the instantaneous current reserve of the distributor as the maximum rated current of the distributor less the instantaneous current flowing from the distributor to the plurality of load circuits, (b) means for limiting the instantaneous current of the variable load circuit to: (i) the full load current of the variable load circuit, if the instantaneous current reserve is greater than zero, and (ii) the sum of the full load current of the variable load circuit plus the instantaneous current reserve, if the instantaneous current reserve is less than or equal to zero.

[0027] The invention might be applied to various forms of distributor, including for example, a distribution panel and a distribution transformer.

[0028] In some cases, at least one aspect of the means for measuring and the means for limiting might function in an analog manner.

[0029] More particularly, the means for measuring or the means for limiting might include: respective means for representing the respective currents as respective voltages; and means for comparing or means for summing the respective voltages.

[0030] Furthermore, the means for representing the maximum rated current of the distributor could include means for generating a reference voltage; the means for representing the instantaneous current flowing from the distributor to the plurality of load circuits could include means for generating an instantaneous voltage signal in response to the instantaneous current; and the means for measuring the instantaneous current reserve of the distributor could include means for summing the reference voltage and the instantaneous voltage signal.

[0031] In this way, the means for representing the full load current of the variable load circuit might include means for generating a second reference voltage and the means for limiting the instantaneous current of the variable load circuit might include means for comparing the instantaneous current reserve to ground, wherein in response, if the instantaneous current

reserve is greater than ground, the means for limiting is operable to limit the instantaneous current of the variable load circuit to the full load current of the variable load circuit, and, if the instantaneous current reserve is less than or equal to ground, the means for limiting is operable to limit the instantaneous current of the variable load circuit to the sum of the full load current of the variable load circuit plus the instantaneous current reserve.

[0032] In some cases, at least one aspect of the means for measuring and the means for limiting might function in a digital manner.

[0033] More particularly, the means for measuring and the means for limiting could include: means for representing the respective currents as binary values and means for operating upon the binary values. Thus, the means for representing the maximum rated current of the distributor could include a memory register; the means for representing the instantaneous current flowing from the distributor to the plurality of load circuits could include an analog to digital converter coupled to a current sensor; and the means for measuring the instantaneous current reserve of the distributor could include means for subtracting the instantaneous current flowing from the distributor from the maximum rated current of the distributor.

[0034] Furthermore, the means for representing the full load current of the variable load circuit could include a second memory register and the means for limiting the instantaneous current of the variable load circuit could include means for comparing the instantaneous current reserve to zero, wherein if the instantaneous current reserve is greater than zero, the means for limiting is operable to limit the instantaneous current of the variable load circuit to the full load current of the variable load circuit whereas if the instantaneous current reserve is less than or equal to zero, the means for limiting is operable to limit the instantaneous current of the variable load circuit to the sum of the full load current of the variable load circuit plus the instantaneous current reserve.

[0035] The means for limiting might include means for issuing a limit signal in response to the measured instantaneous current reserve circuit. The means for issuing might

include means for issuing the limit signal to a current limiter coupled to the variable load or integrated with the variable load, perhaps wirelessly. The means for limiting might include means for issuing the limit signal to a current limiter at the head of the variable load circuit or a current limiter integrated with the distributor at the head of the variable load circuit.

5 **[0036]** The means for issuing the limit signal might include a pulse-width modulator, for example a pulse-width modulator that is operable in accordance with the SAE J1772 standard.

[0037] At least one of the means for measuring and the means for limiting could be responsive to a user-input signal, including a user-input signal generated remote from the
10 distributor.

[0038] Similarly, at least one of the means for measuring and the means for limiting could be responsive to a safety signal, including a safety signal that is feedback from the means for issuing, perhaps as a safety signal in accordance with the SAE J1772 standard.

[0039] By extension, the means for limiting the current of the variable load
15 circuit could include means for limiting the respective currents of a plurality of variable load circuits. In this way, the means for limiting the respective currents of a plurality of variable load circuits could include means for sharing the instantaneous current reserve by sharing an instantaneous reserve current from the distributor, perhaps applying means for multiplexing the instantaneous reserve current.

20 **[0040]** In some cases, the means for measuring the instantaneous current reserve of the distributor might include means for measuring the instantaneous current reserve of the distributor as the maximum rated current of the distributor less the instantaneous current flowing from the distributor in the phase corresponding to the phase of the variable load circuit.

[0041] In some cases where the distributor is configured for at least one of split-
25 phase and multi-phase supply and the variable load circuit is configured as a multi-phase load, the means for measuring the instantaneous current reserve of the distributor could include means

for measuring the instantaneous current reserve of the distributor as the maximum rated current of the distributor less the largest of the instantaneous currents flowing from the distributor in each of the multiple phases supplying the variable load.

[0042] One aspect of the invention pertains to an arrangement wherein a current
5 sensor is attached to, connected to or placed in proximity of, a wire or circuit breaker carrying a current to be measured in the main circuit of a distribution panel. The output of the current sensor provides a signal that can be either voltage- or current-based and which varies with the current flowing in the main circuit. This signal may be described as a measured signal.

[0043] The measured signal is conditioned to generate a limit signal that provides
10 an electrical load connected to one or more of the branch circuits of distribution panel with a measure of the current available to it at any point in time.

[0044] The limit signal can be either a value corresponding to the total electrical
current available to the load, or a value corresponding to the incremental electrical current still available, over and above the amount of current being consumed by the load, or a value by
15 which the load's consumption has to be reduced.

[0045] One aspect of the invention pertains to the sensor being connected to one
phase of the main power circuit when the limit signal applies to a single-phase load or charger.

[0046] Another aspect of the invention pertains to a dual current sensor wherein
each of two separate current sensors is attached to, connected to or placed in proximity to one
20 phase or one current-carrying section of a distributor in a split-phase main power circuit when the measured signal is destined for a dual-phase load. The dual current sensor provides two separate signals, each behaving as the limit signal for the single-phase case. In the case of multi-phase circuits there may be additional sensors as needed. The measured signals for this arrangement may be combined or individualized into a set of signals or a single limit signal
25 depending on the current load or battery charger requirements.

[0047] Another aspect of this invention provides for a signal-wire routing of the sensor or dual sensor either measured or limit signal that can be used by the load, for example a battery charger connected to a battery, to sense total available or incrementally available charging current. This routing can either be a dedicated wire or one of the power line cables. In the latter case signal transport mechanisms such as the household X10 standard may be used, assuming properly filtered electrical noise sources in any of the branch circuits. Alternatively, computer communications standard signaling circuits may be used where the limit signal serves other purposes as well.

[0048] Another aspect of this invention provides for an alternate wireless method of transmitting the limit signal or signals from the sensor or the dual sensor to a location suitable for use by the electrical load or charging circuit.

[0049] A further aspect of this invention provides an optional current sensor that is attached to, connected to or placed in proximity of, the circuit carrying the current to be measured in the branch circuit that is connected to the electrical load or charger to be controlled. The design, installation and conditioning of this sensor are similar to that of the main circuit current sensor. It may be used by itself to enable generic electric loads to implement consumption safety set points where additional receptacles, perhaps mistakenly, share the same branch circuit. Other safety features are mentioned in the various embodiments.

[0050] Another aspect of this invention provides for a current control method and apparatus external to the circuitry of the current load or charger to be controlled. The method would use the limit signal as gate input to power-control equipment such as insulated gate bipolar transistors (IGBT); unmodified chargers would derive their current from this equipment without the need for internal modifications, as opposed to controlling current flow within the low-voltage circuitry inside the charger, which is another aspect.

[0051] This invention further provides for the modulation of any of the above limit, conditioned sensor signals with time-of-day parameters. The time-of-day value could

either further limit or condition the sensor signals subject to other obligations. This arrangement could also adapt to diurnal fluctuations in the price of electric power.

[0052] This invention also includes the concept of modifying any electrical load or charger circuitry to accept measured current sensor data from the main circuit distributor directly with any of the above-mentioned means, so that its circuitry can provide its own implementation of the sensor data signal conditioning or limit signal. In view of current work by the SAE on new standards for electric vehicles, the signal would be conditioned to act as a load-shedding signal similar to that envisioned by electric utilities and would be an input to the EVSE (electric vehicle service equipment) equipment.

[0053] The current capacity rating of an electrical power circuit is limited to the lesser of the current carrying capacity of its wires and devices and the rating of the circuit breaker connected to the supply. The arrangement of the present invention increases the degrees of freedom available in the installation of these circuits. For example, wire gauge for 80A may be installed where a 40A breaker services the circuit, or a new line is required, but limited to a conservative rating based on normal circuit panel considerations. Sometimes it can also be much more cost-effective to extend an existing heavy-duty circuit to a new location and use sub-panels to service existing equipment on it.

[0054] This invention provides a method and apparatus that measures the electrical current flow in one circuit breaker and makes that data available to a load applied to a different circuit breaker within the same distribution panel. It can be applied to indicate the maximum current supply available to an electric vehicle battery charger and enables the charger to adjust its current consumption accordingly. In effect the invention implements a form of electrical load shedding, or more precisely, modulated demand balancing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0055] Other advantages of the present invention will be readily appreciated, as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

5 [0056] Figure 1 is a functional block diagram of a first embodiment of the present invention, operable to allocate current from a distributor to a single variable load, and including means for measuring the instantaneous current reserve of the distributor and means for limiting the instantaneous current of the variable load circuit.

[0057] Figure 2 is a functional block diagram detailing the means for limiting of
10 Figure 1, including a current limiter.

[0058] Figures 3a - 3d are functional block diagrams of the variable load circuit of Figure 1, showing various couplings for the current limiter.

[0059] Figure 4 is a schematic diagram of a substantially analog implementation of the embodiment of Figure 1.

15 [0060] Figure 5 is a block diagram of a substantially digital implementation of the embodiment of Figure 1, the implementation including a microcontroller.

[0061] Figure 6 is a block diagram of a second embodiment of the present invention, illustrating a master-slave configuration adapted for allocating current from a distribution panel to a plurality of variable loads.

20 [0062] Figure 7 is a block diagram of a third embodiment of the present invention, illustrating a master-slave configuration adapted for allocating current from a distribution panel to a plurality of variable loads subject to the condition of a distribution transformer feeding the distribution panel.

[0063] Figure 8 is a block diagram of a fourth embodiment of the present
25 invention, illustrating a master-slave configuration adapted for allocating current from a plurality

of distribution panels to a plurality of variable loads subject to the condition of a distribution transformer feeding the distribution panels.

DETAILED DESCRIPTION OF THE INVENTION

5 First Embodiment

[0064] Referring to the Figures, wherein like numerals indicate corresponding parts throughout the several views, *Figure 1* shows an apparatus for allocating current **20** from a distributor **22**, having a maximum rated current, among a plurality of load circuits **24** including a variable load circuit **24_a** that benefits from a full load current allocation but is operable at a lower
10 current allocation.

[0065] The apparatus **20** includes means for measuring the instantaneous current reserve of the distributor **26** and means for limiting the instantaneous current of the variable load circuit **28** to the full load current of the variable load circuit **24_a**, if the instantaneous current reserve is greater than zero, and the sum of the full load current of the variable load circuit **24_a**
15 plus the instantaneous current reserve, if the instantaneous current reserve is less than or equal to zero.

[0066] In this embodiment, the means for measuring **26** measures the instantaneous current reserve of the distributor **22** as the maximum rated current of the distributor **22** less the instantaneous current flowing from the distributor **22** to the plurality of
20 load circuits **24**. Those skilled in the art will recognize that the invention could be applied to measuring and limiting other capacities and combinations of capacities than an illustrated in this specific example.

[0067] As detailed in *Figure 2*, the means for limiting the instantaneous current of the variable load circuit **28** includes means for issuing **30** a limit signal in response to the
25 measured instantaneous current reserve and a current limiter **32** operable to limit current in the variable load circuit **24_a** in response to the limit signal.

[0068] The means for issuing **30** may include a pulse-width modulator **34**, for example one that operates in accordance with the SAE J1772 standard. In the embodiment illustrated, the means for issuing **30** includes means for wirelessly issuing the limit signal **36**.

[0069] The current limiter **32** might be any device that limits current in response to a signal, for example a power transistor.

[0070] Those skilled in the art will recognize that the means for issuing **30** might merely convey the limit signal or might also generate and/or process the limit signal. To this end, the means for issuing **30** might be a simple conductor for conducting a signal representing the measured current reserve, or else it might include processing, coupling and/or transmitting components, such as the pulse-width modulator **34** and the means for wirelessly issuing **36**.

[0071] Those skilled in the art will also recognize that the means for issuing **30** and the current limiter **32** might be combined.

[0072] As shown in *Figure 3*, the current limiter **32** may be variously: integrated with the distributor **22** at the head of the variable load circuit **24_a**, located at the head of the variable load circuit **24_a** discrete from the distributor **22**, coupled to the variable load **24_a** at the tail of the variable load circuit **24_a**, or integrated with the variable load **24_a**.

First Embodiment -- Substantially Analog Implementation

[0073] *Figure 4* shows an implementation of the embodiment of *Figure 1*, wherein the means for measuring **26** and the means for limiting **28** function in a substantially analog manner, for example including means for representing the relevant currents as voltages **38** and means for comparing or summing respective voltages **40**.

[0074] More particularly in this implementation, the means for representing the maximum rated current of the distributor **38_a** includes means for generating a reference voltage **42**, the means for representing the instantaneous current flowing from the distributor to the plurality of load circuits **38_b** includes means for generating an instantaneous voltage signal in

response to the instantaneous current **44**, and the means for measuring the instantaneous current reserve of the distributor **26** includes means for summing the reference voltage and the instantaneous voltage signal **40_a**.

[0075] The means for representing the full load current of the variable load circuit **38_γ** includes means for generating a second reference voltage **46** and the means for limiting the instantaneous current of the variable load circuit **28** includes means for comparing the instantaneous current reserve to ground **40_β**, wherein in response, if the instantaneous current reserve is greater than ground, the means for limiting **28** is operable to limit the instantaneous current of the variable load circuit **24_α** to the full load current of the variable load circuit **24_α**, and if the instantaneous current reserve is less than or equal to ground, the means for limiting **28** is operable to limit the instantaneous current of the variable load circuit **24_α** to the sum of the full load current of the variable load circuit **24_α** plus the instantaneous current reserve.

[0076] In still greater detail, a current sensor **52**, in this implementation a split-core sensor **52**, senses the current flowing through the distributor **22** to the plurality of load circuits **24** and in response generates a current that is converted into a representative DC voltage “F” by the means for generating an instantaneous voltage signal in response to the instantaneous current **44**, in this implementation a voltage divider.

[0077] A first operational amplifier **58** is arranged in a voltage follower configuration as a means for representing the maximum rated current “R” of the distributor **22** as a DC voltage set by a first potentiometer **60**.

[0078] Both these voltages “F” and “R” are compared in a second operational amplifier **62** to provide a measure of the instantaneous current reserve of the distributor **22** “(F-R)”.

[0079] A third operational amplifier **64** is also configured as a voltage follower as a means for representing the maximum rated current “r” of the variable load circuit **24_α** as a DC voltage set by a second potentiometer **66**.

[0080] Both these voltages “(F−R)” and “r” are compared in a fourth operational amplifier 68 to provide a limit signal “f”, which may be defined as:

$$[0081] \quad f = \begin{cases} r - (F - R) & \text{for } F \geq R \\ r & \text{for } F < R \end{cases}$$

5 [0082] The implementation is effectively calculating maximum permissible current flow “f” to the variable load circuit 24_a. It does this by clamping the low voltage rail in the operational amplifiers 58, 62, 64, 68 to ground, particularly the second operational amplifier 62. This arrangement prevents the value “(F−R)” from becoming negative. The main current flow through the distributor 22 (represented by “F”) includes the
10 branch flow through the variable load circuit 24_a (represented by “f”). This implementation provides a limit signal that reacts to the step changes in current flow in the distributor 22.

First Embodiment -- Substantially Digital Implementation

[0083] *Figure 5* shows an implementation of the embodiment of *Figure 1*,
15 wherein the means for measuring 26 and the means for limiting 28 function in a substantially digital manner, for example including means for representing the respective currents as binary values 38 and means for operating upon the binary values 40.

[0084] More particularly, in this implementation the means for representing the maximum rated current of the distributor 38_a includes a memory register 48 and the means for
20 representing the instantaneous current flowing from the distributor to the plurality of load circuits 38_b includes an analog to digital converter 50 coupled to one or more current sensors 52.

[0085] The means for measuring the instantaneous current reserve of the distributor 26 includes means for subtracting the instantaneous current flowing from the distributor from the maximum rated current of the distributor 40_a.

[0086] The means for representing the full load current of the variable load circuit 38_γ includes a second memory register 54, and the means for limiting the instantaneous current of the variable load circuit 28 includes means for comparing the instantaneous current reserve to zero 40_β, such that if the instantaneous current reserve is greater than zero, the means for limiting 28 is operable to limit the instantaneous current of the variable load circuit 24_α to the full load current of the variable load circuit 24_α, but if the instantaneous current reserve is less than or equal to zero, the means for limiting 28 is operable to limit the instantaneous current of the variable load circuit 24_α to the sum of the full load current of the variable load circuit 24_α plus the instantaneous current reserve.

[0087] In still greater detail, the apparatus 20 is built around an electronic microcontroller 70 having a processor 71 in communication with a random access memory 72 (RAM 72), an erasable programmable read only memory 74 (EPROM 74), and a plurality of input/output devices 76, including a serial port 78, a plurality of analog read ports 80, the pulse-width modulator 34, and the analog to digital converter 50.

[0088] Two current sensors 52 measure each of the two phases in the AC mains supply at the distributor 22 and their output is sent to the analog to digital converter 50 for access by the processor 71.

[0089] User communications are enabled via the serial port 78 and either a remote TTY device 82 or a page server 84 in communication with a remote browser 86. This arrangement allows capacity rating values for the distributor 22 and the variable load circuit 24_α to be user-adjusted, a process that normally happens once and where the values are recorded in the registers 48, 54 in the EPROM 74. Thus it will be seen that at least one of the means for measuring 26 and the means for limiting 28 is responsive to a user-input signal, including a user-input signal generated remote from the distributor 22.

[0090] The pulse-width modulator 34 generates a unipolar 5V pulse-width modulated waveform whose positive duty cycle is proportional to the amount of current the

variable load circuit **24_a** may draw, as supplied through a charger interface **88**. This duty cycle is calculated under program control subject to the values obtained from the current sensors **52** and the capacity rating stored in the EPROM **74** memory registers **48**. This limit signal is sent to the charger interface **88** via a signal converter **90**, which converts it into a bipolar +/- 12V limit
5 signal. In some implementations, the charger interface **88** is referred to as EVSE (electric vehicle service equipment) according to the SAE J1772 protocol.

[0091] This embodiment also implements a safety and control mechanism, wherein the charger interface **88** returns a potentially modified form of the limit signal to a signal splitter **92**. The splitter **92** converts the limit signal into two positive pulse-
10 trains so that they can be measured independently by the analog read ports **80** in the microcontroller **70** as positive voltage levels; if these levels fall within pre-programmed limits, battery charging can proceed. Thus it will be seen that at least one of the means for measuring **26** and the means for limiting **28** is responsive to a safety signal, including a safety signal that is feedback from the means for issuing **30**, for example a safety signal in accordance with the SAE
15 J1772 standard.

[0092] In order to carry out the above actions, the microcontroller **70** is programmed to perform the following actions. First it determines if the capacity rating values have been set and are valid by reading the onboard EPROM **74**. Once proper values have been entered and stored, the PWM generator **34** generates a limit signal of arbitrary duty cycle.

20 [0093] The processor **71** then reads the return values delivered by the signal splitter **92** to the analog read ports **80**. If the stream corresponding to the negative pulses is less than 12V, the processor **71** simply keeps checking regardless of any other conditions. If the positive pulse is about 12V, again the processor **71** simply keeps checking regardless of any other conditions. Once the positive stream drops to at most 9V, the processor **71** tests the inputs
25 of the current sensors **52** and makes the limit signal active by setting its duty cycle accordingly, while continuing to check for changes in the value of the return streams as above.

[0094] If the positive return stream is between 3V and 6V, the processor 71 may also engage a primary relay [not shown] in the charger interface 88 that serves to indicate to the EVSE that charging current may flow. If the positive stream returns to 12V, the relay [not shown] is disengaged and the limit signal returns to its nominal testing value.

5 [0095] While the limit signal is active, the processor 71 accepts no remote user input through the TTY device 82 or the page server 84; however, a user may set or modify the values of the capacity ratings locally; i.e. it is necessary for a user to demonstrate that he is actually at the equipment site, not somewhere remote, for example by throwing a mechanical switch on the hardware board.

10 [0096] The calculations carried out by the microcontroller 70 while the limit signal is active are basically the same as those done in analog form in the embodiment of *Figure 4*. However in this alternate embodiment there are two current sensors 52 (one per phase) so that the equivalent single reading used for calculations here is the voltage delivered by the higher of the two. In this way, the means for measuring the instantaneous current reserve of the distributor 26 includes means for measuring the instantaneous current reserve of the distributor 26 as the maximum rated current of the distributor 22 less the instantaneous current flowing from the distributor 22 in the phase corresponding to the phase of the variable load circuit 24_a. Similarly, where the distributor 22 is configured for at least one of split-phase and multi-phase supply and the variable load circuit 24_a is configured as a multi-phase load, the means for measuring the instantaneous current reserve of the distributor 26 could include means for measuring the instantaneous current reserve of the distributor 26 as the maximum rated current of the distributor 22 less the largest of the instantaneous currents flowing from the distributor 22 in each of the multiple phases supplying the variable load 24_a.

[0097] In detail, call the maximal phase current flowing in the distributor 22 “I” and let its capacity rating be “R”. Calculate “R – I” and add that value to the current “i_b”

flowing in the variable load circuit **24_a**, which has a capacity rating of “**r**”. If “(**r**−**ib**)” is negative, then that value is added to “**ib**” and the limited current is set to the new value of “**ib**”.

[0098] Safety standards for such EV charger circuits call for dedicated

wiring. In situations where special measures are desired to override these standards with non-

5 dedicated circuits, an additional current sensor **52** (not shown) could be added to the charger circuit itself. Its reading when converted to current units would then be an accurate measure of the actual current flowing in that circuit and it is this value that would be used in processor **71** calculations. Specifically, at each iteration the allowed charger current as calculated above is adjusted by the difference between its prior value and the actual current flow “**ib**”, since “**ib**”
10 now may include extraneous current flows.

Second Embodiment

[0099] *Figure 6* shows a second embodiment of the apparatus **20**, which

may be viewed as an extension of the implementation of the first embodiment implementation

15 shown in *Figure 5*. In general, the second embodiment of the apparatus **20** introduces certain cost saving measures when multiple variable loads **24_a** are connected to the same distributor **22**, in this case a distribution panel **22_a**.

[00100] The apparatus **20** includes both a master microcontroller module

70_a and a slave microcontroller module **70_b**. The slave module **70_b** is similar to the basic

20 elements of the first embodiment, but without user interface components. There is one such slave module **70_b** for each variable load circuit **24_a** such that there exists means for limiting **28** the respective currents of a plurality of variable load circuits **24_a**.

[00101] Since the most expensive components of the first embodiment are

the current sensors **52**, in order to reduce their aggregate cost, only the master microcontroller

25 module **70_a** is configured with them in the second embodiment and the slave microcontroller modules **70_b** have none. The second most expensive component in the first embodiment is the

page server **84**, which in the second embodiment is again only required by the master microcontroller **70_a**. The page server **84** is modified to allow user settings of capacity rating for each of the variable load circuits **24_a** individually, as well as for the distributor **22** as a whole.

[00102] The master module **70_a** and each of the slave modules **70_b** each
 5 include a communications unit **93** for communicating among themselves and which in aggregate form a multiplexor **94**, in this embodiment a wireless one, so as to provide means for sharing the instantaneous current reserve -- in other words an instantaneous reserve current from the distributor **22** -- in this case by multiplexing the instantaneous reserve current.

[00103] Some of the functions of the master module **70_a** are to read current
 10 levels from the sensors **52**, to ensure that all user capacity settings are accounted for and are valid, to receive data from the microcontroller modules **70** and to monitor active slave modules **70_b**. The master module **70_a** informs each slave module **70_b** about the value “**r**” of its capacity rating and calculates the applicable current values for each slave module **70_b** and informs the respective slave module **70_b**. In detail for “**N**” active variable load circuits **24_a**, call the current
 15 flowing in the distributor **22** “**I**” and let its capacity rating be “**R**”. Instruct each respective active slave module **70_b** that “ $F = \frac{(R - I)}{N}$ ”.

[00104] The slave modules **70_b** do not process user settings, as was the case in the first embodiment, but instead use the current readings supplied by the master module **70_a**. In detail, each respective slave module **70_b** receives the above calculated value “
 20 $F = \frac{(R - I)}{N}$ ” and add it to the respective current “**ib**” flowing in its respective variable load circuit **24_a** that has a rating “**r**”. If the value “**(r - ib)**” is negative, then it is added to “**ib**” and the limited current is set to this new value of “**ib**”.

[00105] This second embodiment also takes care of the unlikely situation that chargers are connected to variable load circuits **24_a** of different ratings. The wireless

multiplexer can be replaced with a hard-wired multiplexer chip that uses the SPI port-select capabilities of the microcontroller **70**, where wiring distances and topologies allow.

Third Embodiment

5 **[00106]** *Figure 7* shows a third embodiment of the apparatus **20**, which may be seen as extending concepts of the second embodiment to include current sensing using a sensor **52** applied to a distributor **22** in the form of a distribution transformer **22_β** servicing a distribution panel **22_α** which supplies load circuits **24**, including at least one variable load circuit **24_α**. Although these transformers **22_β** already include fault protection, the reason for this sensor

10 **52** is improved safety and allocation: distribution transformers **22_β** typically have a rating which is less than the aggregate rating of the distribution panels **22_α** that they supply.

[00107] The third embodiment of the apparatus **20** again comprises a master microcontroller module **70_α** and one or more slave microcontroller modules **70_β**. The function of the master module **70_α** is to carry out all the current sensing and to inform the slave

15 modules **70_β** of its calculations. The programming of this unit is therefore almost identical to that described in the second embodiment, except that it only differs in the calculations it performs. In detail, for “N” active variable load circuits **24_α**, call the current flowing in the transformer **22_β** “IX” and let its capacity rating be “RX”. Call the current flowing in the distribution panel **22_α** “I” and let its capacity rating be “R”. Then, add “(RX – IX)” to the distribution panel **22_α**

20 flow “I” and instruct the slave modules **70_β** that “ $F = \frac{(R - I)}{N}$ ”. The slave modules **70_β** then operate substantially as in the second embodiment.

Fourth Embodiment

[00108] *Figure 8* shows a fourth embodiment of the apparatus **20**, which

25 may be seen as leveraging common aspects of prior embodiments while extending concepts to

include configurations with multiple distributors **22**, for example multiple distribution panels **22_a**, and multiple variable load circuits **24_a** serviced by a common distribution transformer **22_β**.

[00109] The apparatus **20** comprises a master microcontroller module **70_a**, at least one intermediate microcontroller module **70_γ**, and at least one slave microcontroller module **70_β**. Each intermediate module **70_γ** is associated with a respective distribution panel **22_a** while each slave module **70_β** is associated with a respective variable load circuit **24_a**. A slave module **70_β** may be substantially similar to the slave modules **70_β** of the third embodiment. Each of the respective modules **70** has a communication unit **93** through which it may communicate with other modules **70**.

10 [00110] The master module **70_a** is in communication with a transformer **22_β** current sensor **52**. The function of the master module **70_a** is to carry out the current sensing on the distribution transformer **22_β** using a dual sensor **52** and to inform the intermediate modules **70_γ** of the instantaneous current readings. It also requires a page server **84** accessible through browser **86** to carry out user settings of circuit parameters for the transformer **22_β**, the
15 distribution panels **22_a**, and the variable load circuits **24_a**. The user settings in this embodiment also include a map of communications addresses that reflect the links in the hierarchy. This ensures that communications are maintained only between appropriate pairs of nodes in the network. A portion of this communications map is sent to each intermediate module **70_γ**.

[00111] The intermediate modules **70_γ** carry out distribution panel **22_a** current
20 sensing via sensors **52**. They use that data together with the instantaneous transformer **22_β** current communicated to them to calculate the available current for the respective slave modules **70_β** they are responsible for. Each distribution panel **22_a** supplies one or more variable load circuits **24_a** and thus each intermediate module **70_γ** is associated with one or more respective slave modules **70_β**.

25 [00112] It is the responsibility of each respective slave module **70_β** to notify its respective intermediate module **70_γ** that it is active so that the intermediate module **70_γ** can

determine of the number of active variable load circuits **24_a**. Similarly, it is the responsibility of each intermediate module **70_γ** to pass back its calculated values to the master module **70_α**. These are bottom-up messages that are serviced periodically. All other messages are top-down. All messages use a header to indicate the message type and a value corresponding to that type in the message body; the messages use a termination character to allow processing variable length messages.

[00113] The master module **70_α** current computations are as follows. For a total of “N” active variable load circuits **24_a**, call the transformer **22_β** current “IX” and let its capacity rating be “RX”. Calculate “ $\frac{(RX-IX)}{N}$ ” as the transformer **22_β** current reserve per active

10 variable load circuit **24_a**. The master module **70_α** can therefore instruct each intermediate module **70_γ** having “n” respective active variable load circuits **24_a** that its allocation of the transformer **22_β** current reserve is

$$\text{“FX”} = \frac{(RX-IX)}{N} \times n.$$

[00114] In receipt of its respective allocation “FX” from the transformer **22_β**,
 15 each respective intermediate module **70_γ** calculates its allocation per variable load circuit **24_a** “F” in terms of the instantaneous current “I” measured passing through the distribution panel **22_α**, the rating capacity “R” of the distribution panel **22_α** and the number “n” of active variable load circuits **24_a** being supplied by the distribution panel **22_α**. The intermediate module **70_γ** adds “FX” to “I” and calculates “ $\frac{R-I}{n}$ ” as a value of “F”, which is communicated to each slave
 20 module **70_β**.

[00115] Each slave module **70_β** operates substantially similarly to the slave modules **70_β** of the third embodiment.

Virtual Capacity Ratings

[00116] In the analog implementation of the first embodiment, remote modification of the circuit capacity ratings is absolutely precluded by the design. Mentioned in the digital implementation of the first embodiment and implicit in the second through fourth
5 embodiments, it is precluded as a safety measure, since it would generally be undesirable to have just anybody with access to a browser **86** modify these values incorrectly.

[00117] However, a case based on additional safety reasons can be made that user equipment enrolled in utility-driven demand response programs be able to support remote variable capacity rating. This safety feature is not just local, but could protect the distributed
10 electrical grid when under heavy charger loads **30, 24_a**.

[00118] To this end, the preceding digital implementations and embodiments could be modified with the concept of virtual capacity ratings - for the transformer **22_b**, the distribution panel **22_a**, and the variable load circuits **24_a**.

[00119] A virtual capacity rating is a concept that allows the remote control of the
15 capacity rating values stored in the registers **48, 54** of a microcontroller **70**, as long as the remotely controlled values don't violate the settings introduced using the safety measures mentioned previously. It is another method of modulating the charger load, combining demand control and supply control simultaneously.

[00120] This feature depends on each microcontroller **70** having a unique
20 hardware address. A guaranteed method to implement this relies on the use of the page server **84** MAC address. The MAC address can be used directly, or it can be an index into a database that points to the real address, whatever that may be. In the absence of access to the MAC address, a unique address would have to be assigned to each page server **84** and/or microcontroller **70**.

[00121] Under this arrangement, a responsible authority such as the electric utility
25 can be given access to each unique address to set the virtual capacity rating(s) depending on resource availability or based on policy.

[00122] In the unlikely case that the granularity of the unique address does not match the desired granularity of control, the control software and the microcontroller 70 can be modified to provide the desired match. As an example, a remote supervisory virtual capacity rating control command to a particular variable load circuit 24_a can be translated by the
5 microcontrollers 70 in a hierarchy and routed within the local network composed of nodes as described in the previous embodiments. Such a demand response message would incorporate not just the MAC address, but also a node identifier.

[00123] The handling of virtual capacity ratings is accomplished once again with the use of EPROM 74 memory registers 48. Each microcontroller 70 directly or indirectly
10 addressed with remote commands would be responsible for verifying that virtual capacity ratings do not violate EPROM-recorded real rating values. In addition, the messaging software in prior embodiments would have to support additional messages; some of them would be designed to accumulate the actual current consumption of all chargers in the network at a node that could transmit that value to the utility.

[00124] Finally, the page server 84 must also be modified to be receptive to input
15 at all times, particularly during the active pulse-width modulator 34 phase. When activated, virtual capacity ratings would override real capacity ratings in all calculations presented in previous embodiments through.

[00125] Obviously, many modifications and variations of the present invention are
20 possible in light of the above teachings and may be practiced otherwise than as specifically described while within the scope of the appended claims. In addition, the reference numerals in the claims are merely for convenience and are not to be read in any way as limiting.

[00126] There are many possible embodiments for this invention. The operation of these embodiments has been discussed on the basis that standard distribution panels 22_a using
25 thermally protected circuits have a slower response time to over-current conditions than the sensors 52 employed in this invention to measure current. Further, over-current protection

margins in circuit breakers are very generous and can range to 10-times normal current levels. The first described preferred embodiment senses and responds to over-current steps that are estimated to be at most 40% of the main breaker current rating in a single-phase environment.

[00127] Electrical current sensors **52** might be magnetically coupled to the wires feeding circuit breakers, but they could also be electrically connected, or the signal could be derived from a power sensor **52** that provides (directly or indirectly) current flow values, or from any part of the breaker or distribution panel **22_a** or more generally distributor **22** that provides this data.

[00128] Finally, although a number of alternatives have been presented for allocating the taught functionality between hardware and software and between various modules, those skilled in the art will recognize that many other alternative allocations exist and that there is broad latitude for making such allocations, and as such, allocations other than those expressly described will still fall within the scope of the invention as defined in the claims.

CLAIMS

What is claimed is:

1. A method of allocating current from a distributor having a maximum rated current among a plurality of load circuits including a variable load circuit that benefits from a full load current allocation but is operable at a lower current allocation, comprising:

(a) measuring the instantaneous current reserve of the distributor as the maximum rated current of the distributor less the instantaneous current flowing from the distributor to the plurality of load circuits;

(b) limiting the instantaneous current of the variable load circuit to:

- (i) the full load current of the variable load circuit, if the instantaneous current reserve is greater than zero; and

(ii) the sum of the full load current of the variable load circuit plus the instantaneous current reserve, if the instantaneous current reserve is less than or equal to zero.

2. A method as set forth in claim 1, wherein at least one aspect of measuring and limiting is performed in an analog manner.

3. A method as set forth in claim 1, wherein at least one of measuring and limiting includes:

- (a) representing the respective currents as respective voltages; and
- (b) at least one of
- (i) comparing; and
- (ii) summing
- the respective voltages.

4. A method as set forth in claim 3, wherein:

(a) representing the maximum rated current of the distributor includes setting a reference voltage;

(b) representing the instantaneous current flowing from the distributor to the plurality of load circuits includes generating an instantaneous voltage signal in response to the instantaneous current; and

(c) measuring the instantaneous current reserve of the distributor includes summing the reference voltage and the instantaneous voltage signal.

10 5. A method as set forth in claim 4, wherein

(a) representing the full load current of the variable load circuit includes setting a second reference voltage; and

(b) limiting the instantaneous current of the variable load circuit includes comparing the instantaneous current reserve to ground, and

15 (i) if the instantaneous current reserve is greater than ground, limiting the instantaneous current of the variable load circuit to the full load current of the variable load circuit, and

(ii) if the instantaneous current reserve is less than or equal to ground, limiting the instantaneous current of the variable load circuit to the sum of the full load current
20 of the variable load circuit plus the instantaneous current reserve.

6. A method as set forth in claim 1, wherein at least one aspect of measuring and limiting is performed in a digital manner.

7. A method as set forth in claim 6, wherein at least one of measuring and limiting includes:

- (a) representing the respective currents as binary values; and
- (b) operating upon the binary values.

5

8. A method as set forth in claim 7, wherein:

(a) representing the maximum rated current of the distributor includes setting a memory register;

(b) representing the instantaneous current flowing from the distributor to the plurality of load circuits includes reading the output of an analog to digital converter coupled to a current sensor; and

(c) measuring the instantaneous current reserve of the distributor includes subtracting the instantaneous current flowing from the distributor from the maximum rated current of the distributor.

15

9. A method as set forth in claim 8, wherein

(a) representing the full load current of the variable load circuit includes setting a memory register; and

(b) limiting the instantaneous current of the variable load circuit includes comparing the instantaneous current reserve to zero, and

(i) if the instantaneous current reserve is greater than zero, limiting the instantaneous current of the variable load circuit to the full load current of the variable load circuit, and

(ii) if the instantaneous current reserve is less than or equal to zero, limiting the instantaneous current of the variable load circuit to the sum of the full load current of the variable load circuit plus the instantaneous current reserve.

10. A method as set forth in claim 1, wherein limiting includes issuing a limit signal in response to the measured instantaneous current reserve circuit.

5 11. A method as set forth in claim 10, wherein limiting includes issuing the limit signal to a current limiter coupled to the variable load.

12. A method as set forth in claim 11, wherein limiting includes issuing the limit signal to a current limiter integrated with the variable load.

10

13. A method as set forth in claim 11, wherein issuing includes issuing wirelessly.

14. A method as set forth in claim 10, wherein limiting includes issuing the limit signal to a current limiter at the head of the variable load circuit.

15

15. A method as set forth in claim 10, wherein limiting includes issuing the limit signal to a current limiter integrated with the distributor at the head of the variable load circuit.

16. A method as set forth in claim 10, wherein the limit signal is pulse-width
20 variable.

17. A method as set forth in claim 16, wherein the limit signal is pulse-width variable in accordance with the SAE J1772 standard.

25 18. A method as set forth in claim 1, wherein at least one of measuring and limiting is responsive to a user-input signal.

19. A method as set forth in claim 18, wherein the user-input signal is generated remote from the distributor.

5 20. A method as set forth in claim 1, wherein at least one of measuring and limiting is responsive to a safety signal.

21. A method as set forth in claim 10, wherein at least one of measuring and limiting is responsive to a safety signal that is feedback from the limit signal.

10

22. A method as set forth in claim 21, wherein the safety signal is a safety signal in accordance with the SAE J1772 standard.

23. A method as set forth in claim 10, wherein limiting the current of the variable
15 load circuit includes limiting the respective currents of a plurality of variable load circuits.

24. A method as set forth in claim 23, wherein limiting the respective currents of a plurality of variable load circuits includes sharing the instantaneous current reserve.

20 25. A method as set forth in claim 24, wherein sharing the instantaneous current reserve includes sharing an instantaneous reserve current from the distributor.

26. A method as set forth in claim 25, wherein sharing an instantaneous reserve current includes multiplexing the instantaneous reserve current.

25

27. A method as set forth in claim 1, wherein the method of allocating current from a distributor is a method of allocating current from a distribution panel.

28. A method as set forth in claim 1, wherein the method of allocating current from a
5 distributor is a method of allocating current from a distribution transformer.

29. A method as set forth in claim 1, wherein measuring the instantaneous current reserve of the distributor includes measuring the instantaneous current reserve of the distributor as the maximum rated current of the distributor less the instantaneous current flowing from the
10 distributor in the phase corresponding to the phase of the variable load circuit.

30. A method as set forth in claim 1, wherein:

(a) the distributor is configured for at least one of split-phase and multi-phase supply;

15 (b) the variable load circuit is configured as a multi-phase load; and

(c) measuring the instantaneous current reserve of the distributor includes measuring the instantaneous current reserve of the distributor as the maximum rated current of the distributor less the largest of the instantaneous currents flowing from the distributor in each of the multiple phases supplying the variable load.

20

31. An apparatus for allocating current from a distributor having a maximum rated current among a plurality of load circuits including a variable load circuit that benefits from a full load current allocation but is operable at a lower current allocation, comprising:

(a) means for measuring the instantaneous current reserve of the distributor as the maximum rated current of the distributor less the instantaneous current flowing from the distributor to the plurality of load circuits;

(b) means for limiting the instantaneous current of the variable load circuit to:

(i) the full load current of the variable load circuit, if the instantaneous current reserve is greater than zero; and

(ii) the sum of the full load current of the variable load circuit plus the instantaneous current reserve, if the instantaneous current reserve is less than or equal to zero.

32. An apparatus as set forth in claim 31, wherein at least one of the means for measuring and the means for limiting functions in an analog manner.

33. An apparatus as set forth in claim 31, wherein at least one of the means for measuring and the means for limiting includes:

(a) respective means for representing the respective currents as respective voltages; and

(b) at least one of

(i) means for comparing; and

(ii) means for summing

the respective voltages.

34. An apparatus as set forth in claim 33, wherein:

(a) the means for representing the maximum rated current of the distributor includes means for generating a reference voltage;

(b) the means for representing the instantaneous current flowing from the distributor to the plurality of load circuits includes means for generating an instantaneous voltage signal in response to the instantaneous current; and

(c) the means for measuring the instantaneous current reserve of the distributor includes means for summing the reference voltage and the instantaneous voltage signal.

10

35. An apparatus as set forth in claim 34, wherein

(a) the means for representing the full load current of the variable load circuit includes means for generating a second reference voltage; and

(b) the means for limiting the instantaneous current of the variable load circuit includes means for comparing the instantaneous current reserve to ground, and wherein in response,

(i) if the instantaneous current reserve is greater than ground, the means for limiting is operable to limit the instantaneous current of the variable load circuit to the full load current of the variable load circuit, and

(ii) if the instantaneous current reserve is less than or equal to ground, the means for limiting is operable to limit the instantaneous current of the variable load circuit to the sum of the full load current of the variable load circuit plus the instantaneous current reserve.

20

36. An apparatus as set forth in claim 31, wherein at least one of the means for

25 measuring and the means for limiting functions in a digital manner.

37. An apparatus as set forth in claim 36, wherein at least one of the means for measuring and the means for limiting includes:

- (a) means for representing the respective currents as binary values; and
- (b) means for operating upon the binary values.

5

38. An apparatus as set forth in claim 37, wherein:

(a) the means for representing the maximum rated current of the distributor includes a memory register;

(b) the means for representing the instantaneous current flowing from the distributor to the plurality of load circuits includes an analog to digital converter coupled to a current sensor; and

(c) the means for measuring the instantaneous current reserve of the distributor includes means for subtracting the instantaneous current flowing from the distributor from the maximum rated current of the distributor.

15

39. An apparatus as set forth in claim 38, wherein

(a) the means for representing the full load current of the variable load circuit includes a second memory register; and

(b) the means for limiting the instantaneous current of the variable load circuit includes means for comparing the instantaneous current reserve to zero, and wherein

(i) if the instantaneous current reserve is greater than zero, the means for limiting is operable to limit the instantaneous current of the variable load circuit to the full load current of the variable load circuit, and

(ii) if the instantaneous current reserve is less than or equal to zero, the means for limiting is operable to limit the instantaneous current of the variable load circuit to the sum of the full load current of the variable load circuit plus the instantaneous current reserve.

40. An apparatus as set forth in claim 31, wherein the means for limiting includes means for issuing a limit signal in response to the measured instantaneous current reserve circuit.

5 41. An apparatus as set forth in claim 40, wherein the means for limiting includes means for issuing the limit signal to a current limiter coupled to the variable load.

42. An apparatus as set forth in claim 41, wherein the means for limiting includes means for issuing the limit signal to a current limiter integrated with the variable load.

10

43. An apparatus as set forth in claim 41, wherein the means for issuing includes means for issuing the limit signal wirelessly.

44. An apparatus as set forth in claim 40, wherein the means for limiting includes
15 means for issuing the limit signal to a current limiter at the head of the variable load circuit.

45. An apparatus as set forth in claim 40, wherein the means for limiting includes means for issuing the limit signal to a current limiter integrated with the distributor at the head of the variable load circuit.

20

46. An apparatus as set forth in claim 40, wherein the means for issuing the limit signal includes a pulse-width modulator.

47. An apparatus as set forth in claim 46, wherein the pulse-width modulator operates
25 in accordance with the SAE J1772 standard.

48. An apparatus as set forth in claim 31, wherein at least one of the means for measuring and the means for limiting is responsive to a user-input signal.

49. An apparatus as set forth in claim 48, wherein the user-input signal is generated
5 remote from the distributor.

50. An apparatus as set forth in claim 31, wherein at least one of the means for measuring and the means for limiting is responsive to a safety signal.

10 51. An apparatus as set forth in claim 40, wherein at least one of the means for measuring and the means for limiting is responsive to a safety signal that is feedback from the means for issuing.

52. An apparatus as set forth in claim 51, wherein the safety signal is a safety signal
15 in accordance with the SAE J1772 standard.

53. An apparatus as set forth in claim 40, wherein the means for limiting the current of the variable load circuit includes means for limiting the respective currents of a plurality of variable load circuits.

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54. An apparatus as set forth in claim 53, wherein the means for limiting the respective currents of a plurality of variable load circuits includes means for sharing the instantaneous current reserve.

55. An apparatus as set forth in claim 54, wherein the means for sharing the instantaneous current reserve includes means for sharing an instantaneous reserve current from the distributor.

5 56. An apparatus as set forth in claim 55, wherein the means for sharing an instantaneous reserve current includes means for multiplexing the instantaneous reserve current.

57. An apparatus as set forth in claim 31, wherein the distributor is a distribution panel.

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58. An apparatus as set forth in claim 31, wherein the distributor is a distribution transformer.

59. An apparatus as set forth in claim 31, wherein the means for measuring the instantaneous current reserve of the distributor includes means for measuring the instantaneous current reserve of the distributor as the maximum rated current of the distributor less the instantaneous current flowing from the distributor in the phase corresponding to the phase of the variable load circuit.

20 60. An apparatus as set forth in claim 31, wherein:

- (a) the distributor is configured for at least one of split-phase and multi-phase supply;
- (b) the variable load circuit is configured as a multi-phase load; and
- (c) the means for measuring the instantaneous current reserve of the

25 distributor includes means for measuring the instantaneous current reserve of the distributor as

the maximum rated current of the distributor less the largest of the instantaneous currents flowing from the distributor in each of the multiple phases supplying the variable load.

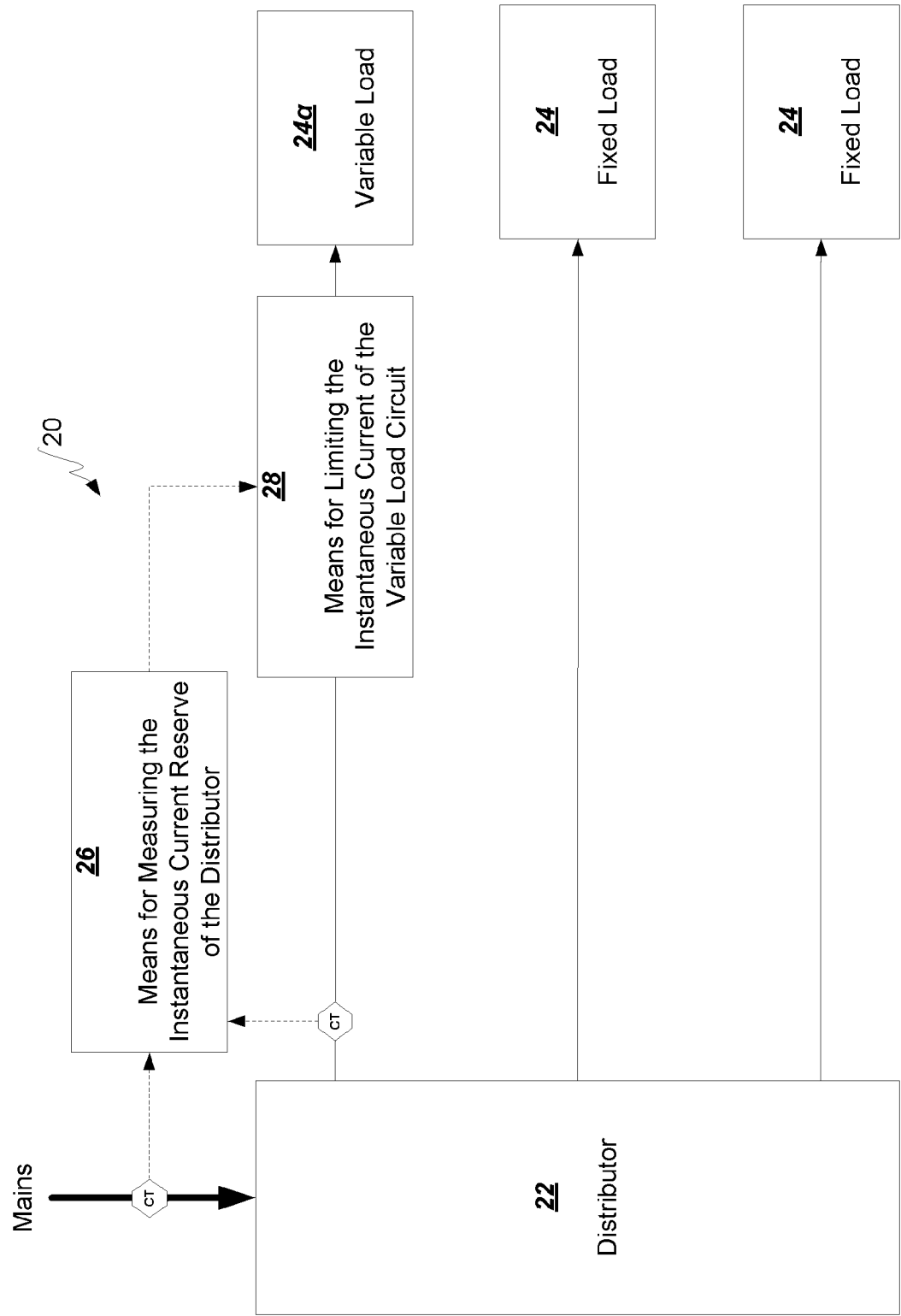


Figure 1

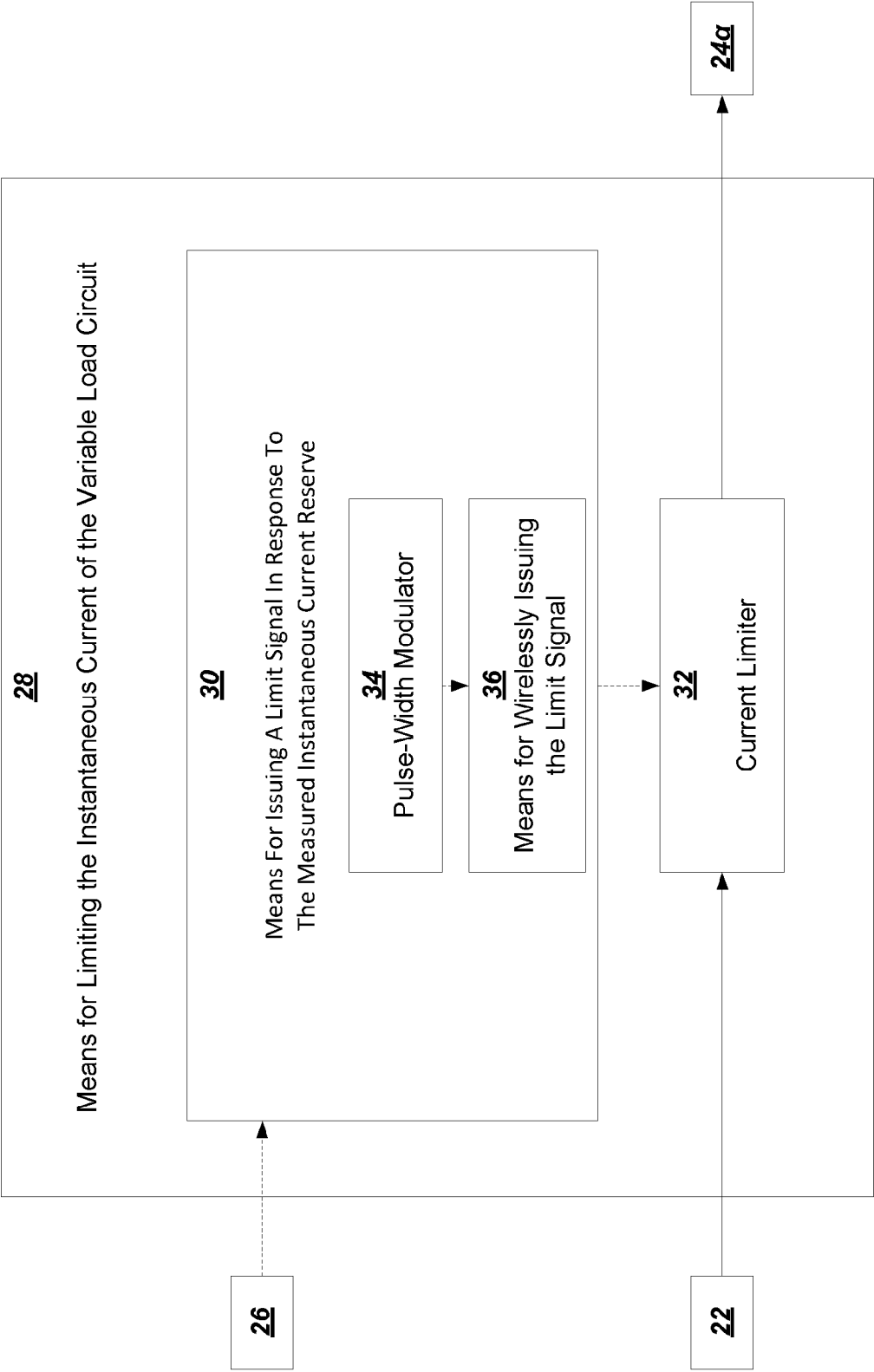


Figure 2

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*Figure 3A**Figure 3B**Figure 3C**Figure 3D*

Figure 3

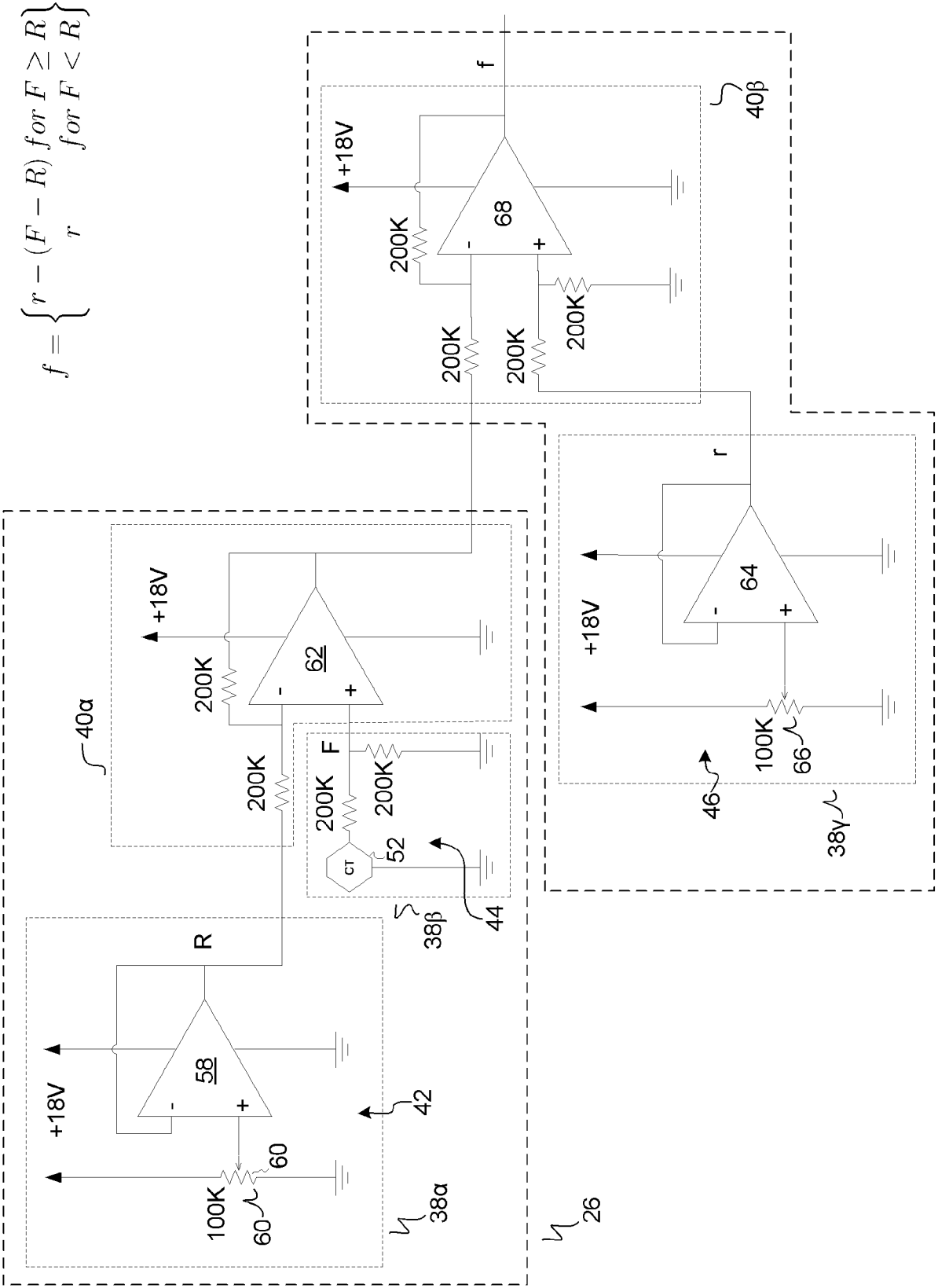


Figure 4

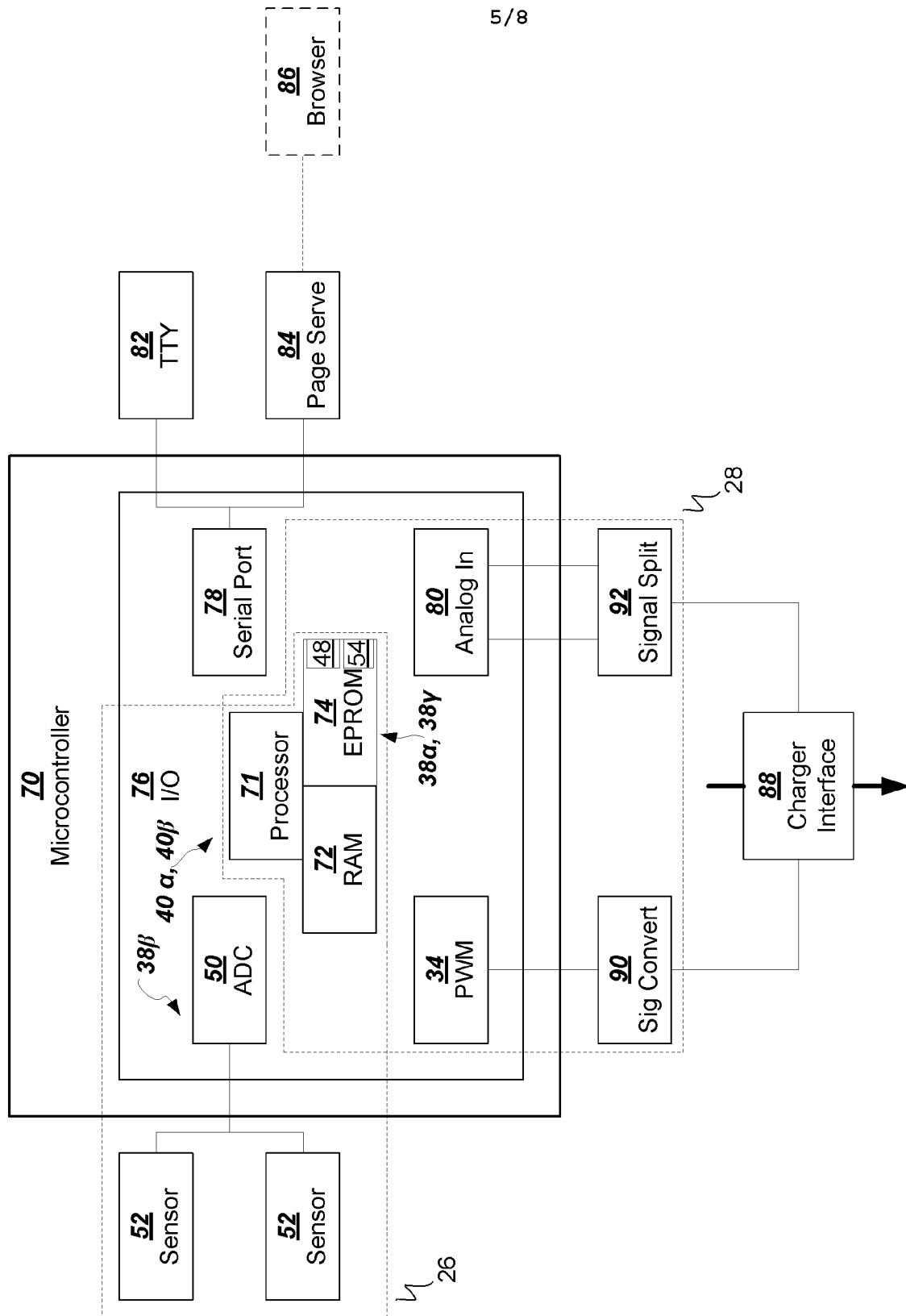


Figure 5

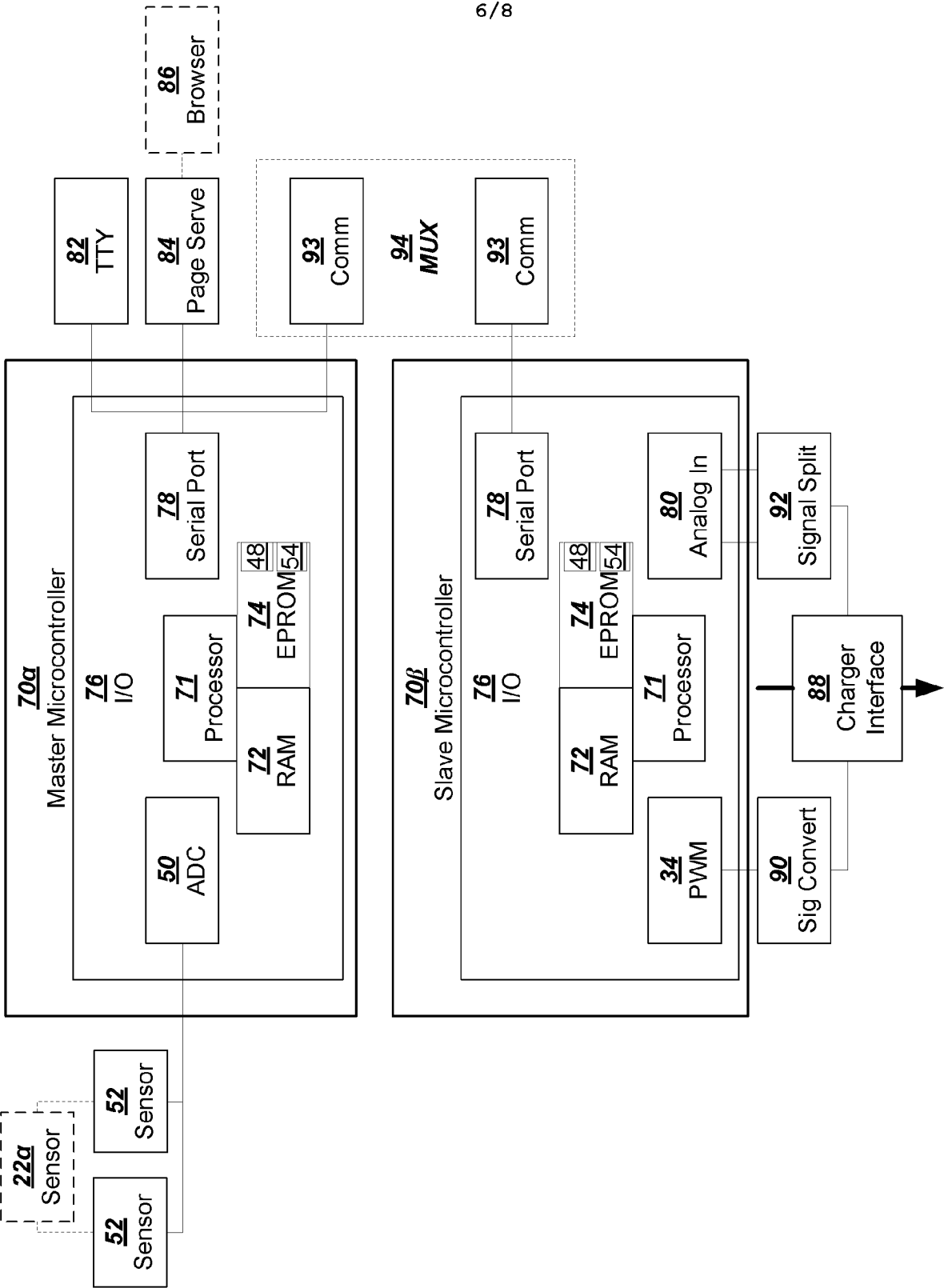


Figure 6

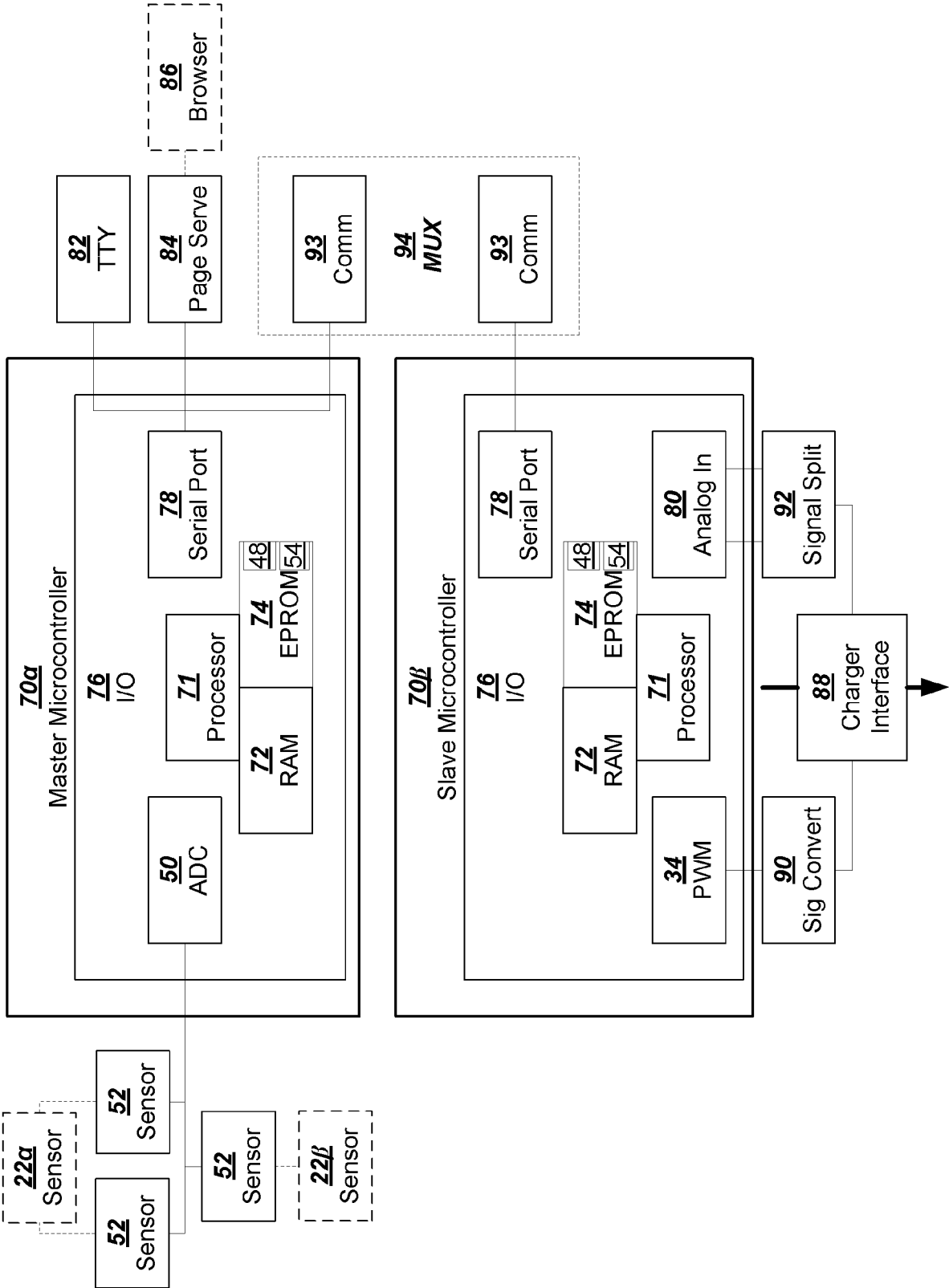


Figure 7

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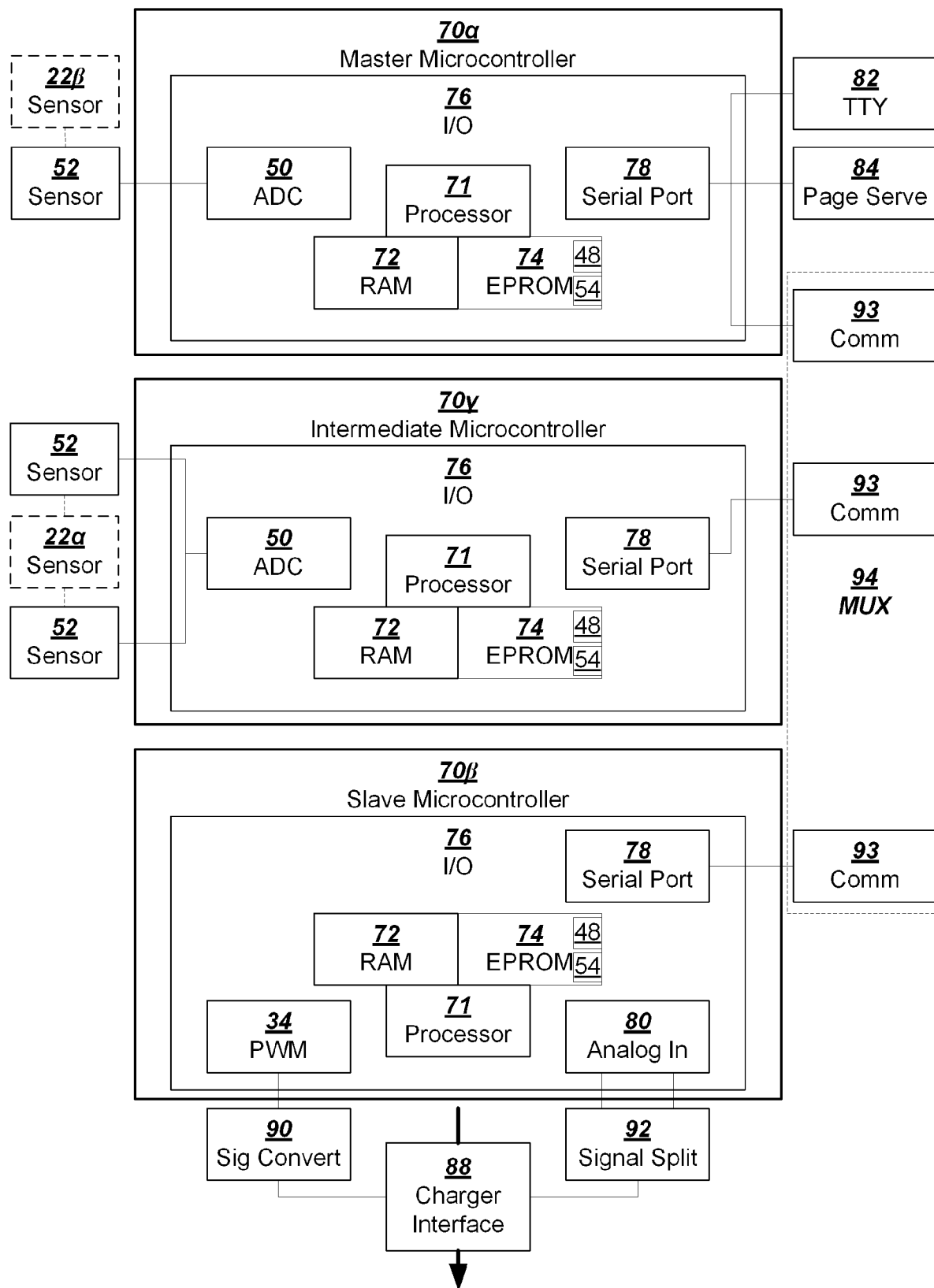


Figure 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2010/000147

A. CLASSIFICATION OF SUBJECT MATTER IPC: H02J 4/00 (2006.01) , H02J 7/00 (2006.01) According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H02J*		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used) Databases searched: Canadian Patent Database, TotalPatent, European Patent Database (EPOQUE), Abstracts of Japan, US Patent Database, WIPO-PCT Publications (Full text) and IEEE publications: (Keywords Only): Current and distributor and (load circuit or "variable load circuit") and full load current and instantaneous current		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US7,514,815 (Paik et al.), 07 Apr 2009 (07-04-2009); -see abstract; -see figs. 1 & 4; -see whole document.	1 - 60
A	US7,274,975 (Miller), 25 September 2007 (25-09-2007) -see abstract; -see figs. 1-3; -see whole document.	1 - 60
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents :	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family	
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)		
"O" document referring to an oral disclosure, use, exhibition or other means		
"P" document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search	Date of mailing of the international search report	
15 October 2010 (15-10-2010)	12 November 2010 (12-11-2010)	
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Authorized officer Rajiv Agarwal (819) 997-2304	

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2010/000147

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		US2009121547A1	14 May 2009 (14-05-2009)
		US7786617B2	31 August 2010 (31-08-2010)

US 7,274,975B2	25 September 2007	US2006276938A1	07 December 2006 (07-12-2006)
		US2007276547A1	29 November 2007 (29-11-2007)
		US7783390B2	24 August 2010 (24-08-2010)
		WO2006132760A2	14 December 2006 (14-12-2006)
		WO2006132760A3	05 July 2007 (05-07-2007)
