APPARATUS FOR AND METHOD OF EVENLY DISTRIBUTING AN ELECTRICAL LOAD ACROSS AN n-PHASE POWER DISTRIBUTION NETWORK

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to an apparatus for and method of evenly distributing the electrical load in a three phase electrical power distribution network.

Presently, many residential homes and commercial facilities receive, at their service entrances, all three phases in a three phase electrical power distribution network provided by an electric utility or power company. In a typical three phase distribution environment each phase supplies one or more branch circuits. The determination of which branch circuit or circuits to wire to each of the three incoming phases is usually made at the time the facility is designed or constructed and is difficult to change once the facility is completed. For example, in a residential facility, different branch circuits might supply the kitchen, living room, bedrooms, etc. with electricity. In a commercial environment, different branch circuits might supply machinery, offices, etc. A problem that arises frequently is how to evenly distribute electrical power across from the three incoming phases, supplied by the electric utility, to all branch circuits. Often, over time, the load topology of a facility will change, sometimes drastically. Some branch circuits become more heavily loaded and others less heavily loaded, due to, for example, movement of machinery on a factory floor, the addition of or movement of high wattage appliances (i.e. refrigerator, electric stove, microwave oven, etc.) in a home. Thus, the load on each of the three incoming phases will also change with the changing load on the branch circuits. A three phase network that was evenly balanced initially might become unbalanced over time.

One solution to this problem is to reassign each branch circuit to an incoming phase to achieve an even load across all three phases by physically rewiring each branch circuit. A disadvantage of this solution

is that it potentially requires the costly rewiring of electrical closets and distribution panels every time the three phases become unbalanced, which might occur frequently. Another disadvantage is that the rewiring typically requires a disruption in power causing a potential problem for utility customers. In addition, this solution only provides a crude mechanism of balancing the load across the three incoming phases. It does not track power consumption on each phase and branch circuit on a frequent basis. The hour to hour and minute to minute changes in electrical loading that occur, which might be large enough to cause major unbalancing across the three incoming phases, pass undetected.

SUMMARY OF THE INVENTION

The present invention provides an apparatus for and a method of evenly distributing the electrical load across all three phases of a three phase power distribution network that overcomes the disadvantages of previous solutions.

According to the teachings of the present invention, there is provided a three phase load distribution system comprising a first, second and third current sensor coupled to a first, second and third phase, respectively, of a three phase electrical power distribution network, the first, second and third current sensors for measuring the electrical current flow through the first, second and third phase, respectively, a plurality of switches, each switch coupled to one of a plurality of branch circuits, each of the plurality of switches for connecting any one of the first, second or third phases to one of a plurality of branch circuits, a plurality of current sensors, each current sensor coupled to one of the plurality of branch circuits, the plurality of current sensors for measuring the electrical current flow through each of the plurality of branch circuits and a processor coupled to the first, second and third current sensors, the plurality of switches and the plurality of current sensors, the processor for controlling

the plurality of switches so that the electrical current flow through the first, second and third phases do not exceed a predetermined threshold.

Further, according to the teachings of the present invention, there is provided a three phase load distribution system comprising a first, second and third current sensor coupled to a first, second and third phase, respectively, of a three phase electrical power distribution network, the first, second and third current sensors for measuring the electrical current flow through the first, second and third phase, respectively, a plurality of switches, each switch coupled to one of a plurality of branch circuits, each of the plurality of switches for connecting any one of the first, second or third phases to one of a plurality of branch circuits, a plurality of current sensors, each current sensor coupled to one of the plurality of branch circuits, the plurality of current sensors for measuring the electrical current flow through each of the plurality of branch circuits and a processor coupled to the first, second and third current sensors, the plurality of switches and the plurality of current sensors, the processor for controlling the plurality of switches so that the differences between the electrical currents, or the ratios of the electrical currents, flowing through each pair of the first, second and third phases do not exceed a predetermined threshold.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. 1 is a block diagram of a 3-phase embodiment of the present invention;

FIG. 1B is a block diagram of a 1-phase embodiment of the present invention;

FIG. 2 is a block diagram of an embodiment of the present invention;

Figure 2B shows a simple implementation of the summing circuit 52, rectifier 54, of Figure 2, combining the two functions in one block, 3-phase rectifier, 524;

Figure 2C is an schematic of a "stationary converter" dc-to-ac inverter;

Figure 2D is an schematic of an improved "stationary converter" dc-to-ac inverter;

Figure 2E shows a three-phase rectifier and an improved "stationary converter" dc-to-ac inverter, with an inductor added to increase input power factor;

Figure 2F replaces the inductor of Figure 2E by a high-power factor controller boost switching regulator to further increase the input power factor;

FIG. 3 is a block diagram of an embodiment of the present invention, combining the features of the systems of Figures 1B and 2F, and further adding communications capability;

FIG. 4 is an alternative to the implementation of Figures 2 and 2B;

FIG. 5 shows a digital electric meter connected to a processor; and,

FIG. 5B illustrates power measurement function hardware.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The principles and operation of the present invention may be better understood with reference to the drawings and the accompanying description.

A block diagram of a device **10** embodying the present invention is shown in Figure 1. Three phase electrical power, represented by $\phi 1$, $\phi 2$, $\phi 3$, is supplied by an electric power utility. Phases $\phi 1$, $\phi 2$, $\phi 3$ are over current protected by a utility circuit breaker **14**. The output of utility circuit breaker **14** appears at the service entrance to a residence or commercial facility. Current sensors **16**, **18**, **20** measure the current flowing through phases $\phi 1$, $\phi 2$, $\phi 3$, respectively. The output of current

sensors 16, 18, 20 are monitored by a processor 12. Processor 12 can be any suitable computing device such as a microprocessor, microcontroller, personal computer, etc.

Each of the three phases output from utility circuit breaker 14 are input to an array of multi-pole switches 22, 24, 26, 28, 30. Each switch has four input terminals. Three terminals are provided, one each for each of the three incoming phases. In addition, a forth terminal is provided that is a no connection terminal (i.e. not connected to anything). The output of switches 22, 24, 26, 28, 30 are input to an array of branch circuit breakers 32, 34, 36, 38, 40, respectively. Control signals CONT1, CONT2, CONT3, CONT4, CONT5, output from processor 12, determine the position of switches 22, 24, 26, 28, 30, respectively. The output of branch circuit breakers 32, 34, 36, 38, 40 pass through an array of current sensors 42, 44, 46, 48, 50, respectively, before supplying each of the five branch circuits with power. Each of the five branch circuits has a neutral line N associated with it. The current measured by current sensors 42, 44, 46, 48, 50 is monitored by processor 12.

Operation of device 10 centers around multi-pole switches 22, 24, 26, 28, 30. In the application of device 10, each branch circuit to be covered has associated with it a switch, a branch circuit breaker and a current sensor. Shown in figure 1 is a load balancing system covering five branch circuits. The present invention, however, could easily be made to cover any number of branch circuits, simply by providing sufficient components.

On a periodic basis, processor 12 acquires the output of current sensors 16, 18, 20, which measure the current flowing though each phase of the supplied three phase power. Processor 12 also monitors the output of current sensors 42, 44, 46, 48, 50, which measure the current flowing through each branch circuit. The time between successive acquisitions of current sensor data is on the order of milliseconds or tens of milliseconds

and is a function of the software controlling processor 12. The data acquired during each data acquisition cycle is not immediately discarded. A finite number of the most recent sets of acquired data are kept in memory, which may be either internal or external to processor 12.

Processor 12 is suitably programmed to periodically acquire data from all current sensors in order to be able to track the load on each phase of the incoming three phase power and on each branch circuit. When the measured current on any one phase exceeds a fixed percentage (e.g., 90%) of an upper current limit setting, processor 12 programs switches 22, 24, 26, 28, 30 so that the total load is fairly equal across the three incoming phases. Since the load on each branch circuit is known, processor 12 can redistribute the branch loads so that the load on each phase is approximately equal. Once the new switch settings are determined, processor 12 outputs switch repositioning commands over control lines CONT1, CONT2, CONT3, CONT4, CONT5 to switches 22, 24, 26, 28, 30, respectively.

During operation of device 10, it is possible that the load on a single branch circuit increases to a level that exceeds the maximum permitted branch current. In response to this possible over current condition, processor 12 can program the branch circuit's corresponding switch to its no connection position. In this position, the branch circuit is electrically disconnected from all three incoming phases. In addition to the over load protection provided by processor 12, conventional branch circuit breakers 32, 34, 36, 38, 40 also provide over current protection for each branch circuit. Device 10 is also able to provide a function conventional circuit breakers are currently not able to provide. Processor 12 can be suitably programmed to predict potential overload conditions before they occur by monitoring the rate of rise in current use by each branch circuit and by each incoming phase. Thus, potential disruptions in

power due to exceeding current limits on an incoming phase can be anticipated and avoided before they occur.

Switches 22, 24, 26, 28, 30 may utilize relays or semiconductor switches (i.e. triacs, silicon controlled rectifiers, etc) as their core switching elements. Each switch decodes its corresponding control signal, received from processor 12, and either connects its output to one of the three incoming phases or totally disconnects its output from all three phases. Switches 22, 24, 26, 28, 30 can switch their output terminals to any incoming phase fast enough so that devices or equipment connected to their corresponding branch circuit do not see any appreciable gap in supplied power and thus, are not adversely effected.

Processor 12 derives its power from $\phi 1$ and the neutral line N of the incoming three phase power. Processor 12 can, however, derive power from any of the three incoming phases. The upper current limit setting can be input to processor 12 any number of ways, all well known in the art. For example, the upper current limit data could be hard coded in a read only memory device, supplied by external dip switch settings, supplied by an external computing device, etc.

While the description of the above embodiment has been given with respect to 3-phases, it will be appreciated that the system of the present invention may be implemented as an n-phase system, for any n. To illustrate this point a 1-phase system, 1000, is shown in Figure 1B. Comparing Figures 1 and 1B, in Figure 1B, two of the input phases have been deleted. The blocks, functionality, and labels are all the same otherwise. The only difference between a one-phase system and a two-or-greater phase system, is that switches 22-30 are only capable of connecting or disconnecting their respective branch circuits to the one phase, and not of changing the branch circuit connection from one phase to a different phase. Thus in a one-phase system, the only option in case of an overloaded system is to select which branch circuit to disconnect, not to

choose to which phase the branch circuit will be reconnected. Thus the present invention applies to power sources of any number of phases, although the usual cases are those of 3-phases and 1-phase, as illustrated in Figures 1 and 1B, respectively.

A second embodiment of the present invention, shown in Figure 2, functions to evenly distribute the load across each phase of a three phase power distribution network. Each phase, $\phi 1$, $\phi 2$, $\phi 3$, of a three phase power distribution network is input to an electrical power summing circuit **52**. Summing circuit **52** functions to receive each incoming phase and combine its current and power handling capacity and subsequently form a single summed output. The output from summing circuit **52** is a single AC electrical voltage having a current capability approximately equal to the sum of the current capabilities of the three incoming phases.

The output of summing circuit **52** is subsequently input to a rectifier **54**. Rectifier **54** rectifies the AC output of summing circuit **54** to essentially a DC level. The current carrying capability of rectifier **54** must be sufficient to handle the total current needs of all the branch circuits combined that are to be covered by device **10**.

The output of rectifier **54** is input to an AC generator **56**. AC generator **56** produces a single phase AC voltage from the DC voltage output by rectifier **54**. The appropriate voltage and frequency (e.g.. 120 V, 60 Hz for the United States) is generated for the particular locality device **10** must operate in.

The output of AC generator **56** is input to branch circuit breakers **32**, **34**, **36**, **38**, **40**, covered by device **10**. The branch circuits are supplied with power by the output of branch circuit breakers **32**, **34**, **36**, **38**, **40**. Although five branch circuits are shown in Figure 2, any number of branches can be covered by device **10**, provided the components have sufficient current ratings for the combined load of all branch circuits.

The actual load distribution in device 10 occurs in summing circuit 52. No matter how the load on each branch circuit increases or decreases it is automatically distributed evenly across all three incoming phases. For example, if the load on any one branch or a group of branches increases by 30%, the corresponding load on each incoming phase increases 10%. Since each incoming phase can be represented by an equivalent low impedance source of current that are identical to each other, if the load on summing circuit 52 increases 30% then this increase appears equally across each of the three incoming phases.

The advantage of this second embodiment over the first embodiment, is that it is less complex, however, it is possibly more costly because expensive components must be utilized for summing circuit 52, rectifier 54 and AC generator 56 that are capable of handling the increased levels of current.

Figure 2B shows a simple implementation of the summing circuit 52, rectifier 54, of Figure 2, combining the two functions in one block, 3-phase rectifier, 524. Figure 2B also shows optional filter capacitor, 58.

It is important to note that the system of Figures 2 and 2B is not a battery backup or uninterruptible power supply system, but rather provides balancing of the loading due to the single phase output circuit, equally, on the three input phases, by the use of the summing circuit, 52. The presence of the summing circuit, 52, results in the loading of the single-phase output circuit to be instantaneously substantially equally shared across all three phases of the input 3-phase power circuit, even without the load-balancing processor, 12,of Figure 1. Hence, the Figure 2 and 2B system provides a performance improvement of the system of the present invention over the implementation of Figure 1. Thus, a power distribution system such as the prior art battery- back-up system disclosed by Fiorina in US 5,477,091, which is a completely one-phase system, including back-up battery, can not render obvious the load-balancing function

accomplished by the Figure 2 and 2B implementation of the present invention.

Further the AC generator, **56**, can be realized as a "stationary converter" -- a dc-to-ac converter or dc-to-ac inverter, without departing from the teaching of the present invention, as an "ac generator" is just a "rotary converter". Thus a stationary converter may also be used as is well known. An example schematic of a "stationary converter" dc-to-ac-inverter is given in Figure 2C. DC input, **213**, from summer rectifier, **524**, powers dc-to-ac inverter, **200**, providing square-wave ac output, **211**, which, after optional low-pass filtering by inductors **208** and **209** and capacitor **210**, becomes sinusoidal ac output, **212**. The example circuit given is a free-running, push-pull oscillator, consisting of a pair of switching transistors, **201** and **202**, the collectors of which are connected to the ends of the primary winding, **207a**, of saturating-core transformer, **207**. The DC input is applied from the center-tap of the primary to the common connection of the emitters of **201** and **202**. Forward-bias is applied to transistors **201** and **202** by resistors **203** and **204**, respectively, which are bypassed for ac by capacitors **205** and **206**, respectively. Feedback is coupled by transformer winding **207c** to the base of transistor **201**, and by transformer winding **207d**, to the base of transistor **202**. The oscillator is free-running at a frequency depending on the saturating transformer design. This is a crude implementation of this type of circuit, and is given as an example, to illustrate the principle of operation. This is known as a Royer Oscillator, after the inventor. The circuit was published in, Royer, G.H., A Switching Transistor AC to DC Converter, Trans AIEE, July '55.

Improved designs, such as inverter, **2000**, in Figure 2D, use a non-saturating transformer for **207**, and add a saturating feedback transformer, **2070**, to the base circuitry. The saturating base feedback transformer then determines the operating frequency of the dc-to-ac inverter. This circuit

does not provide output voltage regulation. In both circuits, the square-wave secondary output peak-to-peak voltage depends on the input dc voltage, and the output frequency depends on the dc input voltage as well as on the saturating transformer characteristics. This improved inverter was published in Jensen, J.L., An Improved Square Wave Oscillator Circuit. Trans. IRE, Vol. CT-4, No. 3, September '57.

The Figure 2 system, then, can be implemented inexpensively by the combination of the three-phase rectifier of Figure 2B with an inverter such as in Figure 2C or 2D. The three-phase rectifier balances the loading equally across each of the three input phases with no computational equipment required.

The system of Figures 2, 2B, and 2C or 2D, may be applied equally well to a 2-phase system, or to a system of greater than 3-phases, i.e., to an "n-phase" power distribution system. Filter capacitor, **58**, and low-pass filter, **208**, **209**, and **210**, may be optionally included, to provide sine-wave output, **212**, depending on the output spectrum required by the load circuitry to be supplied.

The Figure 2, 2B, 2C system is especially well-suited for small-scale installations, say, an individual factory. In this case the use of this implementation of the present invention will be helpful also in reducing the power-factor-correction problem at the entrance to the site, since all the various motor loads, and other non-purely-resistive loads, will have been removed from the ac power entrance to the site, and replaced by one "rectifier-input" circuit. It is possible, that with omission of capacitor **58**, or the use of a very small capacitive for noise filtering alone, that the inductance of primary **207a** of transformer **207**, which will look inductive, will present an improved power factor over that of an installation without this load-balancing circuitry present. This is because a capacitor-input rectifier provides a power factor of about 0.6, while an "infinite-inductor" rectifier circuit ideally provides a power factor of about ninety percent.

The improved form of dc-to-ac inverter of Figure 2D, with a non-saturating collector transformer for 207, and with a separate saturating base transformer, 2070, should provide still greater improvement in site input power factor. Finally, a third variation is a "current-fed" push-pull converter, in which a large inductor is added in series with the dc supply input connection to the center tap of transformer, 207. This would provide increased inductance in the rectifier circuit, further increasing input power factor. A high, near-unity power factor is important to the power utility companies, since this represents a possible savings in power distribution facilities cost, as is well known. Figure 2E shows system, 10, including three-phase rectifier, 524, and an improved "stationary converter" dc-to-ac inverter, 200, with inductor, 2071, added to increase input power factor. A purely resistive load has a power factor of 1.0. Load current phase shift due to non-resistive loads, and distortion due to non-linear loads, reduce the power factor and result in increased facilities cost to the electric company, due to inefficient coupling of electrical energy to the consumer load site.

While the stationary inverter circuits illustrated are very old technology, they represent the simplest, least expensive implementation. Newer push-pull switching regulators, incorporating feedback control circuitry, and with no saturating transformers may be used to implement stationary inverters having input-voltage-independent output voltage and frequency. The implementation of such inverters when operating from low-voltage battery supplies is well known. The design of such circuits for higher input voltage is straightforward, less difficult than the low-voltage input case.

Figure 2F replaces the inductor, 2071, of Figure 2E by a high-power factor controller boost switching regulator, 5242, to further increase the input power factor. The boost regulator, 5242, may employ a high-power-factor controller such as the Unitrode Integrated Circuits

Corporation part number UC1854. This part and its application is well documented in the Unitrode literature, which may be found in Product & Applications Handbook '93-'94, #IC850, Unitrode Integrated Circuits Corporation, 7 Continental Boulevard, Merrimack, NH 03054, USA, Telephone: (603) 424-2410 FAX: (603) 424-3460. Block **5242** provides a regulated DC output voltage, **5244**, to Dc-to-AC inverter, **10**, removing one cause of ac output frequency variations, as well as fixing the output amplitude of DC-to-AC converter, **10**. The capacitor Choldup, **5243**, provides a storage of charge, which permits DC-to-AC inverter, **10**, to continue to provide ac output, **211**, for a few milliseconds after any transient low input line voltage condition. This provides some immunity to short "sags", and provides time for orderly shutdown of loads, if a low-input voltage warning signal is provided by boost regulator, **5242**, as is often done. The UC1854 and similar high-power-factor controllers are capable of providing input power factors to the n-phase power source, of greater than 0.99 when working in a normal single-phase system. With an 3-phase input as illustrated in Figure 2F, the identical circuit should provide an increased input power factor, since the error source known as "cusp distortion", described in the Unitrode literature should not be present when using the controller with an n-phase power source. This is because the additional phases do not permit the minimum input voltage to the high-power-factor boost regulator to momentarily drop to zero, as with a single-phase full-wave bridge rectifier, for example, since the additional phases fill in the "hole" between the two half-cycles of the one-phase input. The cusp distortion is analogous to cross-over distortion in amplifiers, and is removed by the filling-in of the ripple waveform, since the input voltage no longer instantaneously reaches the problematic near-zero-volts low input voltage range.

The 1854 power factor controller and design procedure are described in the following Unitrode IC Corp. literature:

(1) UC1854/2854/3854 High Power Factor Preregulator (1854 Data Sheet)

(2) U-134, UC3854 Controlled Power Factor Correction Circuit Design

(3) DN-39D, Optimizing Performance in UC3854 Power Factor Correction Applications

(4) DN-41, Extended Current Transformer Ranges

(5) U-140, Average Current Mode Control of Switching Power Supplies.

In summary the method of the Figure 2, etc., system for evenly balancing the electrical loading on an n-phase electrical power source includes the steps of:

rectifying said n-phase electrical power source to produce DC voltage source;

connecting said DC voltage source to a dc-to-ac inverter, for generating an ac output voltage;

generating said AC output voltage from said DC voltage;

connecting ac loads to said ac output voltage, thereby supplying an output ac load current to said ac loads;

whereby, said output ac load current is reflected back through said dc-to-ac inverter as a DC load current on said DC voltage source, and whereby said DC load current is in turn reflected back through said n-phase rectifier as an input ac load current on said n-phase electrical power source, said input ac load current being provided equally by said n phases of said n-phase power source by said n-phase rectifier,

thereby balancing said ac output load current equally on said n phases of said n-phase power source.

FIG. 3 is a block diagram of an embodiment of the present invention, combining the features of the systems of Figures 1B and 2F, and further adding communications capability, for example, with the electric company or with the consumer, via communications link, e.g., modem, **3001**. The implementation of the system of Figure 2F is inserted

between utility circuit breaker, 14, of Figure 1B, and the rest of the Figure 1B system, providing automatic load-balancing, and also high power factor, as described above. The Figure 1B system is represented here as n units, of circuitry labelled **1001** ... **1002**, which represent each unit of circuitry associated with each of m branch circuits. These m branch circuit "units" are connected to processor **3012** the same as to processor **12** in Figure 1B, and are not only controlled in the same way by processor **3012**, to limit maximum loading on the n-phase utility circuit by limiting the maximum load current provided by dc-to-ac inverter, **10**, but processor **3012** has additional capabilities as will be described. Now, modem, **3001**, is connected by bilateral data bus, **3004**, to processor **12**. Modem, **3001**, is preferably connected by RJ11 interface, **3002**, to the central office telephone line, **3003**. Modem, **3001**, provides communications capability, for example with the electric utility company or with the consumer.

In addition the preprogrammed control by processor **12** of the connecting and disconnecting of loads, i.e, branch circuits, in response to current measurements performed by sensors, **18** and **42m**, processor **3012** also accepts programming to control adding and dropping loads as a function of time, e.g., time-of-day or day-of-week. Also the dropping of loads in case of a power-line overload condition, and the reconnecting of loads, may be performed according to priorities pre-programmed by the consumer into processor, **3012**. Thus, the electric power consumer may exercise control over the operation of equipment at his site, even in his absence. Further, processor **3012** may report data to the electric company, communicating via modem **3001**. Yet further, the electric company may make inquiries of the processor, e.g., concerning loading of each of the phases in an n-phase system as in Figure 1, or of loading on each branch circuit, in any of the implementations illustrated in the Figures. Also, the electric company or the consumer may issue commands to the processor, e.g., to connect or disconnect loads, thereby exercise

control over the loads in the consumer's facility via modem, **3001**, and processor, **3012**, and the electric company or the consumer may remotely reprogram processor, **3012**, via modem, **3001**. While a wired telephone line connection is shown, the use of cellular phone, or other wireless communication method of realizing a communications link with processor **3012** is equally included within the scope of the invention.

Figure 4 shows an alternative implementation **5400** of the combination of blocks **52** and **54** of Figure 2, for a three-phase system, as an example of an n-phase system, with n=3. In Figure 4, each phase is first rectified, in rectifiers **401-403**, with each rectifier output serving as the input to a separate power-factor correction (PFC) module, **405- 407**, such as discussed above, e.g., using a UC1854 or similar controller. The outputs of the n power-factor correction modules are connected together, and to holdup capacitor **409**, providing a DC output, **410**. The n PFC modules have a common load-sharing buss interconnection, **408**, as is discussed in the Unitrode literature with respect to their UC1907 Load Share Controller integrated circuit, for example, and with respect to switching regulator controllers, such as the UC1842. The purpose of the load-sharing buss is to assure that each PFC module provides an equal share of the load current as each other PFC module, plus-or-minus a tolerance, say 10% or less.

The advantage of the Figure 4 implementation over that of Figures 2 and 2B, is that the Figure 4 implementation more certainly provides both improved load balancing on the n phases, and improved power factor on each of the n phases.

Figure 5 shows the additional connection of a digital electric meter, **5001**, to a processor, **3012**, such as processor **3012** of Figure 3. Digital electric meter **5001** is a digital kilowatt-hour meter, which records cumulative electric power consumption. The processor, **3012**, has associated connection **3004** to modem **3001**, which is preferably connected

via interface 3002 to central office telephone line 3003. With this arrangement, the electric power usage of the consumer facility is made available through the processor and communications link for transmission to an inquiring location, e.g., the electric utility power company.

In another embodiment, implicitly included in Figure 3, the current sensors **18** and **42n** are continuously monitored by processor **3012**, and in conjunction with simultaneous voltage measurements at the locations of the current sensors, the instantaneous power consumption may be calculated as is well known, and may be continually summed, "integrated", in processor **3012**, to maintain the cumulative electric power consumption of the facility. The necessary hardware for each power measurement is illustrated in Figure 5B, showing current sensor **518** with output **518I** to processor **3012**, and voltage sensor **5189** with output **5189V** to processor **3012**. Thus the functionality of digital power meter **5001** may be incorporated in the system of Figure 3, and similarly in an n-phase system, such as in Fig.1.

The digital power meter function, whether implemented as a discrete instrument as in Fig. 5, or as implicitly in Fig. 3, as described above, may be useful in any of the systems described herein, even without a communications link, for providing an additional parameter for use in load management.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made. In particular, the usual n-phase case of n=3 has been used an example. In general, the number of phases is not limited to three phases, but may be any number of phases. Further, any form of communications link may be used for the exchange of information between the consumer-site processor and the electric company.

* C L M S *

WHAT IS CLAIMED IS:

1. A three phase electrical load distribution system, comprising:

an electrical power summing circuit coupled to a first, second and third phase of a three phase electrical power distribution network, said electrical power summing circuit for producing a summed output having a current capacity equivalent to the sum of the current capacities of said first, second and third phases;

a rectifier circuit coupled to said electrical power summing circuit, said rectifier circuit for rectifying said summed output to a substantially DC voltage; and

a generator for converting said DC voltage into a substantially AC voltage.

2. The system of claim 1, wherein said AC voltage is single phase and has a predetermined voltage and frequency.

3. A method for evenly distributing the electrical load in a three phase electrical power distribution system, the method comprising the steps of:

summing the electrical power supplied by each phase of a three phase electrical power distribution network thereby producing a summed output;

rectifying said summed output to produce a substantially DC voltage; and

generating a substantially AC voltage from said DC voltage.

4. The method of claim 3, wherein said AC voltage is single phase and has a predetermined voltage and frequency.

5. A three phase electrical load distribution system as in claim 1, wherein said summing circuit and said rectifying circuit are combined as a 3-phase rectifier.

6. A method for evenly distributing the electrical load in a three phase electrical power distribution system, as in claim 3, wherein said summing and said rectifying are combined in a 3-phase rectifier.

7. A three phase load distribution system for evenly distributing an electrical load, present on a plurality of branch circuits, across a three phase power distribution network, comprising:

a first, second and third current sensor coupled to a first, second and third phase, respectively, of the three phase electrical power distribution network, said first, second and third current sensors for measuring electrical currents flowing through said first, second and third phase, respectively;

a plurality of switches, each of said switches coupled to one of the plurality of branch circuits, each of said plurality of switches for connecting any one of said first, second or third phases to one of the plurality of branch circuits;

a plurality of current sensors for measuring electrical currents flowing through each of said plurality of branch circuits; each of said current sensors coupled to one of said plurality of branch circuits; and

a processor coupled to said first, second and third current sensors, said plurality of switches and said plurality of current sensors;

said processor for calculating,

(a) the differences between said electrical currents flowing through each pair of said first, second and third phases, and,

(b) the ratios of said electrical currents flowing through each pair of said first, second and third phases;

said processor for controlling said plurality of switches so that a function selected from the group consisting of (a) the differences between, and (b) the ratios of, said electrical currents flowing through each pair of said first, second and third phases do not exceed a predetermined threshold;

said processor calculating alternative combinations of branches to be connected by said switches to said phases, and said processor controlling re-connection of said branches by said switches to said phases so that functions do not exceed said threhold.

8. An at least one phases load distribution system for evenly distributing an electrical load, present on a plurality of branch circuits, across an at least one phases power distribution network, comprising:

at least one current sensor coupled to at least one phases, respectively, of the at least one phases power distribution network, said at least one current sensor for measuring electrical current flowing through said at least one phase, respectively;

a plurality of switches, each of said switches coupled to one of the plurality of branch circuits, each of said plurality of switches for connecting any one of said at least one phases to one of the plurality of branch circuits;

a plurality of current sensors for measuring electrical currents flowing through each of said plurality of branch circuits;

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each of said current sensors coupled to one of said plurality of branch circuits; and

a processor for controlling said plurality of switches so that said electrical currents flowing through each of said at least one phases does not exceed a predetermined threshold; said processor coupled to said at least one current sensors, said plurality of switches and said plurality of current sensors.

9. An at least one phase load distribution system for evenly distributing an electrical load, present on a plurality of branch circuits, across an at least one phase power distribution network, comprising:

at least one current sensor coupled to at least one phases, respectively, of the at least one phases electrical power distribution network, said at least one current sensors for measuring electrical currents flowing through said at least one phases, respectively;

a plurality of switches, each of said switches coupled to one of the plurality of branch circuits, each of said plurality of switches for connecting any one of said at least one phases to one of the plurality of branch circuits;

a plurality of current sensors for measuring electrical currents flowing through each of said plurality of branch circuits; each of said current sensors coupled to one of said plurality of branch circuits; and

a processor coupled to said first, second and third current sensors, said plurality of switches and said plurality of current sensors;

said processor for calculating,

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(a) the differences between said electrical currents flowing through each pair of said first, second and third phases, and,

(b) the ratios of said electrical currents flowing through each pair of said first, second and third phases;

said processor for controlling said plurality of switches so that a function selected from the group consisting of (a) the differences between, and (b) the ratios of, said electrical currents flowing through each pair of said first, second and third phases do not exceed a predetermined threshold;

said processor calculating alternative combinations of branches to be connected by said switches to said phases, and said processor controlling re-connection of said branches by said switches to said phases so that functions do not exceed said threshold.

10. A n-phase electrical load balancing system, comprising:

(a) a dc-to-ac inverter for converting DC voltage into AC voltage, having an ac output load circuit, and a dc input connection; and,

(b) an n-phase rectifier circuit with input coupled to an n-phase power source having n phases, and output coupled to said dc-to-ac inverter, said rectifier circuit for

(1) rectifying said n-phase power source to a substantially DC voltage, and for

(2) balancing the loading of said dc-to-ac inverter on said rectifier output circuit equally on said n phases of said n-phase power source,

thereby, balancing loading of said ac output load circuit equally on said n input phases of said n-phase power source.

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11. A n-phase electrical load balancing system as in claim 10, further comprising:

(c) a power-factor-improvement circuit connected in series between said output of said n-phase rectifier and said dc input connection of said dc-to-ac inverter, said circuit selected from the list consisting of (1) an inductor, and (2) a high-power-factor controller switching regulator.

12. A method for evenly balancing the electrical loading on an n-phase electrical power source, the method comprising the steps of:

rectifying said n-phase electrical power source to produce DC voltage source;

connecting said DC voltage source to a dc-to-ac inverter, for generating an ac output voltage;

generating said AC output voltage from said DC voltage;

connecting ac loads to said ac output voltage, thereby supplying an output ac load current to said ac loads;

whereby, said output ac load current is reflected back through said dc-to-ac inverter as a DC load current on said DC voltage source, and whereby said DC load current is in turn reflected back through said n-phase rectifier as an input ac load current on said n-phase electrical power source, said input ac load current being provided equally by said n phases of said n-phase power source by said n-phase rectifier,

thereby balancing said ac output load current equally on said n phases of said n-phase power source.

13. A three phase load distribution system for evenly distributing an electrical load, present on a plurality of branch circuits, across a three phase power distribution network, comprising:

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a first, second and third current sensor coupled to a first, second and third phase, respectively, of the three phase electrical power distribution network, said first, second and third current sensors for measuring electrical currents flowing through said first, second and third phase, respectively;

a plurality of switches, each of said switches coupled to one of the plurality of branch circuits, each of said plurality of switches for connecting any one of said first, second or third phases to one of the plurality of branch circuits;

a plurality of current sensors for measuring electrical currents flowing through each of said plurality of branch circuits; each of said current sensors coupled to one of said plurality of branch circuits;

a processor for controlling said plurality of switches so that said electrical currents flowing through each of said first, second and third phases does not exceed a predetermined threshold; said processor coupled to said first, second and third current sensors, said plurality of switches and said plurality of current sensors; and,

a communications link connected to said processor for providing communications capability.

14. A three phase load distribution system for evenly distributing an electrical load, present on a plurality of branch circuits, across a three phase power distribution network, comprising:

a first, second and third current sensor coupled to a first, second and third phase, respectively, of the three phase electrical power distribution network, said first, second and third current sensors for measuring electrical currents flowing through said first, second and third phase, respectively;

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first, second and third circuit breakers coupled to said first, second and third phases, respectively;

a plurality of switches, each of said switches coupled to one of the plurality of branch circuits, each of said plurality of switches for connecting any one of said first, second or third phases to one of the plurality of branch circuits;

a plurality of circuit breakers, each coupled to one of the plurality of branch circuits;

a plurality of current sensors for measuring electrical currents flowing through each of said plurality of branch circuits; each of said current sensors coupled to one of said plurality of branch circuits;

a processor for controlling said plurality of switches so that said electrical currents flowing through each of said first, second and third phases does not exceed a predetermined threshold; said processor coupled to said first, second and third current sensors, said plurality of switches and said plurality of current sensors; and,

a communications link connected to said processor for providing communications capability.

15. The system of Claim 1, further comprising a communications link.

16. The method of Claim 3, further comprising communicating via a communications link.

17. The system of Claim 7, further comprising a communications link connected to said processor for providing communications capability.

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18. The system of Claim 8, further comprising a communications link connected to said processor for providing communications capability.

19. The system of Claim 9, further comprising a communications link connected to said processor for providing communications capability.

20. The system of Claim 10, further comprising a communications link.

21. The method of Claim 12, further comprising communicating via a communications link.

22. A n-phase electrical load balancing system, comprising:

(a) an n-phase rectifier circuit with input coupled to an n-phase power source having n phases, and output coupled to a dc load, said rectifier circuit for

(1) rectifying said n-phase power source to a substantially DC voltage, and for

(2) balancing the loading of said dc load on said rectifier output circuit equally on said n phases of said n-phase power source,

(b) a power-factor-improvement circuit connected in series between said output of said n-phase rectifier and said dc load.

23. A n-phase electrical load balancing system, comprising:

(a) a separate rectifier for each of the n phases;

(b) a PFC module connected to the output of each said rectifier;

(c) a common output connection between said n PFC modules;

(d) a common load-share buss between said n PFC modules.

24. A system as in Claim 13, further comprising a digital power meter function,

said digital power meter including power measurement capability,

said digital power meter selected from the group consisting of

(a) a digital kilo-watt-hour meter for recording cumulative electric power consumption, and

(b) a combination of a voltage sensor with a said current sensor said voltage and current sensor having outputs to said processor for calculating a power-related measurement selected from the group consisting of instantaneous power consumption and cumulative electric power consumption,

said power meter function for providing an additional parameter for use in load management, and

said power meter function for providing electric power usage of a consumer facility via said communication link.

25. A system as in Claim 14, further comprising a digital power meter function,

said digital power meter including power measurement capability,

said digital power meter selected from the group consisting of

(a) a digital kilo-watt-hour meter for recording cumulative electric power consumption, and

(b) a combination of a voltage sensor with a said current sensor said voltage and current sensor having outputs to said processor for calculating a power-related measurement selected from the group consisting of instantaneous power consumption and cumulative electric power consumption,

said power meter function for providing an additional parameter for use in load management, and

said power meter function for providing electric power usage of a consumer facility via said communication link.

26. The system of Claim 1, further comprising a digital power meter function.

27. The method of Claim 3, further comprising measuring power consumption.

28. The system of Claim 7, further comprising a digital power meter function,

said digital power meter including power measurement capability,

said digital power meter selected from the group consisting of

(a) a digital kilo-watt-hour meter for recording cumulative electric power consumption, and

(b) a combination of a voltage sensor with a said current sensor said voltage and current sensor having outputs to said processor for calculating a power-related measurement selected from the group consisting of instantaneous power consumption and cumulative electric power consumption,

said power meter function for providing an additional parameter for use in load management.

29. The system of Claim 8, further comprising a digital power meter function,

said digital power meter including power measurement capability,

said digital power meter selected from the group consisting of

(a) a digital kilo-watt-hour meter for recording cumulative electric power consumption, and

(b) a combination of a voltage sensor with a said current sensor said voltage and current sensor having outputs to said processor for calculating a power-related measurement selected from the group consisting of instantaneous power consumption and cumulative electric power consumption,

said power meter function for providing an additional parameter for use in load management.

30. The system of Claim 9, further comprising a digital power meter function,

said digital power meter including power measurement capability,

said digital power meter selected from the group consisting of

(a) a digital kilo-watt-hour meter for recording cumulative electric power consumption, and

(b) a combination of a voltage sensor with a said current sensor said voltage and current sensor having outputs to said processor for calculating a power-related measurement selected from the group consisting of instantaneous power consumption and cumulative electric power consumption,

said power meter function for providing an additional parameter for use in load management.

31. The system of Claim 10, further comprising a digital power meter function.

32. The method of Claim 12, further comprising measuring power consumption.

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