(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 June 2009 (11.06.2009)

PCT

(10) International Publication Number
WO 2009/073510 A2

(51) International Patent Classification:
H02J 9/00 (2006.01)

(21) International Application Number:
PCT/US2008/084851

(22) International Filing Date:
26 November 2008 (26.11.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11/948,332 30 November 2007 (30.11.2007) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

(54) Title: SOURCE-TRANSFER SWITCHING SYSTEM AND METHOD

(57) Abstract: A method and system of reducing the time that a load remains un-powered when a power source fails is disclosed. The method includes receiving a sinusoidal input signal from a first power source. Once the signal has been received, a sinusoidal output signal is generated. The sinusoidal output signal defines a lower limit of a deviation range over which the sinusoidal input signal can deviate before a source-transfer from the first power source to a second power source is initiated. Input signal instantaneous value is compared with output signal instantaneous value. When the input signal instantaneous value has fallen below the lower limit of the deviation range is detected, a digital signal is sent to a switch controller in response to the detection, the digital signal causing the load to be coupled to the second power source.

SOURCE -TRANSFER SWITCHING SYSTEM AND METHOD

FIELD OF THE INVENTION

The present invention generally relates to source-transfer switching systems and, more particularly, to a method and system of reducing transfer delays in source-transfer switching systems.

BACKGROUND

Figure 1 is a block diagram of a typical source-transfer system 100. Source-transfer system 100 may be used to switch between a first power source and a second power source when undesirable characteristics, including power disturbances, are sensed in either one of the power sources. The first power source may be a utility source (which may come from a power grid, for example) and the second source maybe back-up generator acting as an emergency source in the event that the utility source fails or is unable to deliver power to a load.

As shown in Figure 1, source-transfer system 100 includes a utility source 101, a transfer switch 104, a transfer switch controller (TSC) 112, a generator 106, a load 109, DC chargers 102 and 105, a DC energy storage 103, a DC/AC inverter 111, and a pair of static switches 110 and 108.

In normal operation mode, utility source 101 provides power to load 109. TSC 112 continuously monitors utility source 101 by computing the root mean square (RMS) voltage. If the RMS voltage from the utility source 101 meets certain quality requirements, TSC 112 maintains static switch 108 in an “on” state and maintains static switch 110 in an “off” state so that load 109 is connected to utility source 101 and not connected to the DC/AC inverter 111.

In the event that TSC 112 senses that utility source 101 has failed, TSC 112 operates to transfer the power source from utility source 101 to generator 106. Generator 106 may act as an emergency source for load 109 while utility source 101 is unable to deliver power to load 109. Generator 106 typically takes 10-15 seconds to stabilize. As generator 106 stabilizes, DC energy storage103 via DC/AC inverter 111 may provide power to load 109 during the transfer interim.

As noted above, TSC 112 computes the RMS voltage of utility source 101. Computing the RMS voltage advantageously enables TSC 112 to ensure that a true utility failure has occurred. Further, computing the RMS voltage advantageously takes into account all harmonics, sags, or swells. Albeit these advantages, computing the RMS voltage, unfortunately, takes about at least ¼ to ½ of a cycle. Consequently, if a failure occurs, the failure won't be detected until at least ¼ to ½ of a cycle after the failure.

Figure 2 illustrates a timing diagram depicting the operation of the source-transfer system 100. At time t_1, utility source 101 fails. And because it takes TSC 112 about at least ¼ of cycle to detect that utility source 101 has failed, this failure, unfortunately, is not detected by TSC 112 until time t_2. As indicated by the magnified inset 201, load 109 remains un-powered for at least ¼ of a cycle.

At time t_2, once TSC 112 detects that utility source 101 has failed, TSC 112 toggles static switches 108 and 110 such that switch 108 is an "off" state and switch 110 is an "on" state so that load 109 is disconnected from utility source 101 and begins receiving power from DC energy store 103 via DC/AC inverter 111. At time t_2, static switch controller also sends a "Start Generator" signal 107 to power generator 106, which turns the generator 106 on. Generator 106 typically takes about 10-15 seconds to stabilize.

At time t_3, when the frequency and phase from generator 106 becomes acceptable, TSC 112 sends a solenoid control signal 116, which operates transfer switch 104 so that generator 106 is coupled to load 109. Typically, transfer switch 104 takes 40-100 milliseconds to switch over, which is indicated as "transfer time" in Figure 2.

At time t_4, when transfer switch 104 has coupled load 109 to generator 106, TSC 112 toggles static switches 108 and 110 to its initial position so that switch 108 is an "on" state and switch 110 is an "off" state. By toggling the static switches 108 and 110, this disconnects load 109 from DC energy store 103 and connects load 109 to generator 106.

As illustrated in Figure 2, source-transfer does not begin until a source failure has been detected. This method of detecting that a source has failed typically takes about at least ¼ of a cycle to determine that a power failure has occurred. During this time, loads that may be critical for certain processes (such as data centers or hospitals with operation rooms), remain un-powered for at least ¼ of a cycle. The source-transfer system illustrated in Figure 1 does not respond to the voltage sags faster than ¼ of a cycle.

SUMMARY

Disclosed herein is an improved method of reducing the time that a load remains un-powered when a source fails. In particular, an overpass controller and associated components are disclosed. The overpass controller ensures that the load is able to quickly receive power from a second power source when a first power source fails or is unable to adequately provide power to the load. The proposed arrangement and method significantly reduces the response time to at least 1/400 of a cycle, which is essential for certain critical power applications.

In one aspect of the invention, a sinusoidal input signal from a first power source is received. A nominal voltage from sinusoidal input signal may be calculated. Based on the calculated nominal voltage, a sinusoidal output signal is generated. The sinusoidal output signal has a magnitude that defines a lower limit of a deviation range over which the input sinusoidal signal can deviate without initiating a source-transfer from the first power source to a second power source. The input signal's instantaneous value is compared with the output signal's instantaneous value. And if at any point in time, the input signal's instantaneous value falls below the lower limit of the deviation range, then, in response, a digital signal is sent to a switch controller. The digital signal causes the load to be coupled to the second power source.

In one embodiment, the sinusoidal output signal has the same phase and frequency as the sinusoidal input signal. Further, while generating the sinusoidal output signal, the input signal and output signal are superimposed on top each other. The sinusoidal input signal has larger amplitude than the amplitude of the sinusoidal output signal. As an example, the output signal may have amplitude that is approximately 15% smaller than the nominal value of the input signal. In addition, when a comparator detects that the input signal's instantaneous value is below the lower limit of the deviation range, then in response to this detection, the comparator sends a digital signal to a switch controller. The switch controller controls switches and disconnects the load from a first power source and connects the load to a second power source. Detecting that the input signal instantaneous value has fallen below the lower limit of the deviation range, and in response, sending a switch control signal to a switch controller, comprises not waiting for a ¼ of a cycle before sending the switch control signal to the switch controller.

Further, the second power source provides power to the load instantaneously and does not need to be stabilized. In addition, the second power source is a DC/AC inverter, which functions as a temporary power source for the load, and in which the DC/AC inverter is connected to DC energy storage.

Further, in the same or in another embodiment, when the comparator sends the digital signal to the switch controller, switch controller, in response to receiving the switch control signal: (i) sends a first control signal to a first static switch, which opens the first static switch and disconnects the load with the first power source and (ii) sends a second control signal to a second static switch, which closes the second switch and couples the load with the second power source. Coupling the load to the second power source occurs after the load is disconnected from first power source. Further, disconnecting the load from the first power source and then coupling the load to the second source causes the load to be un-powered for at least 1/400 of a cycle.

The method further includes detecting that the input voltage signal sags below the output voltage signal for at least ¼ of a cycle, and in response: (i) sending a start-signal to a power generator, which generates a sinusoidal generator signal, (ii) waiting for the power generator to stabilize, (iii) synchronizing the power generator with the second power source, (iv) connecting the load to the power generator, (v) after the load has connected to the load generator, disconnecting the load from the second power source.

In a first embodiment, before synchronizing the power generator with the second power source, the sinusoidal output signal has a first frequency and the sinusoidal generator signal has as second frequency. Further, in one embodiment, synchronizing the generator with the second power source comprises setting the first frequency and the second frequency to have a difference of 0.5 Hz, which allows the second power source to be synchronized to the generator within at least one second. In another embodiment or in the same embodiment, the frequency difference can be greater than or smaller than 0.5Hz. A frequency difference that is greater than 0.5 Hz allows for a faster synchronization but can affect the load requirement.

In another aspect of the invention, an exemplary embodiment may take the form of a system. In accordance with the system, an exemplary overpass controller system includes a synchronizer coupled to a first power source receiving a sinusoidal input signal, the synchronizer generating a sinusoidal output signal, the sinusoidal output signal having a magnitude that is preset according to a ratio of the nominal value of the sinusoidal input signal. Further, the overpass controller system includes a comparator receiving the sinusoidal input signal from the first power source and the sinusoidal output signal from the synchronizer, the comparator comparing the instantaneous values of the sinusoidal input signal from the first power source and the sinusoidal output signal. In addition, the system also includes a static switch controller connected to the comparator, the static switch controller operable to couple a load to a second power source in response to a condition that the instantaneous voltage of the sinusoidal input signal is less than the instantaneous voltage of the sinusoidal output signal.

Further, the comparator functions to send a digital signal to the static switch controller in response to detecting that the instantaneous voltage of the sinusoidal input signal is less than the instantaneous voltage of the sinusoidal output signal. The synchronizer is coupled to a transfer switch controller (TSC) in which the TSC functions to compute root mean square values of the sinusoidal input signal, the TSC sending a synchronization signal that synchronizes synchronizer with a third source. In a preferred embodiment, the third source is a back up generator that needs to be stabilized before the TSC can send a synchronization signal. Further, in the same or a in a different embodiment, the second power source provides power to the load instantaneously and does not need to be stabilized.

These as well as other advantages of various aspects of the presently disclosed methods and apparatus will become apparent to those of ordinary skill in the art by reading the following detailed description, with appropriate reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments are described herein with reference to the drawings, in which:

Figure 1 is a block diagram of a typical source transfer system;

Figure 2 is a timing diagram depicting the operation of the source transfer system illustrated in Figure 1;

Figure 3 is a block diagram depicting components of a source transfer system, in accordance with an exemplary embodiment;

Figure 4 is a representative timing diagram depicting the operation of the source transfer system illustrated in Figure 3;

Figure 5 is a block diagram depicting components of a source transfer system that uses three-phase power supplies, in accordance with exemplary embodiments;

Figure 6 is a flowchart of a method, in accordance with exemplary embodiments; and

Figure 7 is a state diagram, illustrating the different states of a source transfer system, in accordance with exemplary embodiments.

DETAILED DESCRIPTION

Figure 3 is a simplified block diagram of source-transfer system 300 that may be used in accordance with exemplary embodiments. As illustrated in Figure 3, source-transfer system 300 includes an overpass controller 301, a TSC 112, a utility source 101, a load 109, a generator 106, transfer switch 104, DC chargers 102 and 105, a DC energy store 103, static switches 108 and 110, and a DC/AC inverter 111.

Further, as illustrated in Figure 3, overpass controller 301 includes a master synchronizer (MS) 303, a comparator 306, and a static switch controller (SSC) 308. MS 303 generates a continuous sine wave signal that tracks the frequency and phase of utility source 101. In general, overpass controller 301 operates to reduce the time that a load remains un-powered when a power source fails.

It should be understood that the arrangements described herein are for purposes of example only. For example, overpass controller 301 is currently shown to be operating in a single phase system. In this regard, overpass controller 301 may operate in a three phase system. As such, those skilled in the art will appreciate that other arrangements and other elements (e.g., machines, interfaces, functions, orders, and groupings of functions, etc.) can be used instead. Further, many of the elements described herein are functional entities that may be implemented as discrete or distributed components or in conjunction with other components, in any suitable combination or location.

In an exemplary embodiment, two controllers operate concurrently: TSC 112 and overpass controller 301. TSC 112 samples voltage from utility source 101 and computes RMS voltages. Overpass controller 301 operates to compare instantaneous voltage signals. As shown in Figure 3, overpass controller includes the MS 303, a comparator 306, and the SSC 308.

MS 303 receives a sinusoidal input signal 114 from utility source 101. MS 303 may comprise programmable logic controllers and/or micro-controllers. In normal operation, MS 303 generates a sinusoidal signal 304 that tracks the sinusoidal input signal 114 from utility source 101. In one embodiment, signal 304, from MS 303, tracks the phase and frequency of signal 114. In the same or in another embodiment, signal 304 from MS 303 has a smaller magnitude than input signal 114 (i.e., the magnitude of signal 304 is regulated by MS 303). Preferably, the magnitude of signal 304 does not depend on the magnitude of sinusoidal input signal 114. Rather, the magnitude of signal 304 is preset by a predetermined ratio to the nominal load voltage. As an example, the magnitude of signal 304 may be preset by 15% of the nominal voltage of input signal 114.

Comparator 306 receives the output signal 304 from MS 303 and input signal 311 from utility source 101. The magnitude of output signal 304, generated by MS 303, defines a lower limit of a deviation range in which the input signal 311 can deviate before a source-transfer is initiated. Comparator 306 continuously compares the instantaneous values for each of these signals. During normal operation, as shown in Figure 4, signal 311 is within an acceptable deviation range of signal 304. In this condition, comparator yields a low (i.e., a “0”) on signal 307. When signal 311 falls below the lower limit of the deviation as set by the magnitude of output signal 304, either because of a failure in utility source 101 or because of a power disturbance, comparator 306 yields a high (i.e., a “1”) on signal 307.

SSC 308 receives signal 307 from comparator 306 and signal 305 from TSC 112. SSC 308 controls static switches 108 and 110. In particular, SSC 308 sends signals to static switches 108 and 110 and control each of these switches cooperatively such that load 109 is either connected to utility source 101 or to DC/AC inverter 111. Preferably, load 109 is not coupled to both, utility source 101 and DC/AC inverter 111, at the same time.

As long as input signal 114 from utility source 101 is within the deviation range (as set by the output signal 304), comparator 306 produces a low on signal 307, which causes SSC 308 to generate control signals 309 and 310. Control signal 309 causes static switch 108 to be in the “on” state and control signal 310 causes static switch 110 to be in the “off” state. In such a condition, static switch 108 couples load 109 to utility source 101. However, if, at any point in time, the input signal 311 from utility source 101 is not within the acceptable deviation range (e.g., below 15% of the nominal value of the input signal 311) because of a voltage sag or a source outage/failure, comparator 306 produces a high (“1”) on signal 307, which causes SSC 308 to generate control signals 309 and 310, which causes static switch 108 to be in the “off” state, and static switch 110 to be in the “on” state. In such a condition, static switch 110 couples load 109 to DC/AC inverter 111. DC/AC inverter 111 functions as a temporary power source until the input signal 311 returns to an acceptable deviation range.

Turning now to Figure 4, a timing diagram depicting the operation of the source-transfer system 300 is shown. As shown in Figure 4, at time t_1, utility source 101 fails. At this point in time, the instantaneous voltage of signal 311 is less than the instantaneous voltage of signal 304. The comparator 306 produces a signal 307, which activates SSC 308. SSC 308 then toggles both static switches 108 and 110 and initiates a source-transfer from utility source 101 to inverter 111. Utility source 101 becomes disconnected from the load 109, because static switch 108 is now off or open, and inverter 111 becomes the source for load 109, because static switch 110 is now closed. DC energy store 103 becomes the source for load 109. In an exemplary embodiment, static switches 108 and 110 operate such that whenever switch 108 opens, switch 110 closes. And when switch 108 closes, switch 110 opens. Alternatively, in another embodiment, switch 108 may open before switch 110 closes because of a delay in time needed to open and close switches.

Because static switches 108 and 110 are solid-state devices, transfer from utility source 101 to the inverter 111 occurs within approximately 20-40 microseconds. If this load transfer from utility source 101 to inverter 111 was provoked by fast voltage sag (i.e. less than ½ -¼ cycles) the SSC 308 restores the static switches 108 and 110 when the voltage sag disappears. The transfer switch 104 does not change its position during this quick transfer/re-transfer of the load. As shown in Figure 4 by the magnified inset 401, load remains un-powered for about 1/400 of a cycle.

At time t_2, TSC 112 determines that input signal 311 has not been within the predetermined range for at least longer than ¼ of a cycle. TSC 112 can then send a "start generator" signal 107 to generator 106. Generator 106 typically takes about 10-15 seconds to stabilize. During this time, DC/AC inverter 111 continues to steadily provide power to load 109.

At time t_3, voltage and frequency from generator 106 stabilizes and the TSC 112 generates a synchronization signal 302 and then sends the synchronization signal to overpass controller 301. In response to receiving the synchronization signal 302, MS 303 sets the frequency output signal 304 to 0.5 Hz off of the frequency of the generator 106.

It should be understood that the frequency difference of 0.5Hz is being used for purposes of example only. The frequency difference may be greater than or less than 0.5 Hz depending on the application for which the present system and method is being used. For instance, the typical residential and industrial electric power grid lines require power with a frequency of 60±0.5Hz. If the overpass controller 301 (along with TSC 112) is being used for a residential and/or industrial power application, then the frequency difference would be set to 0.5Hz. In this regard, the frequency difference can vary based on the implementation of overpass controller 301 and TSC 112. Typically, a bigger frequency difference allows for a faster synchronization, but it can affect specific load requirements.

The frequency difference (between the frequency of signal 304 and the frequency of signal of generator 106) allows the voltage from inverter 111 to be synchronized to the voltage from generator 106 within 1 second. Once the overpass controller 301 has been synchronized with the generator 106, TSC 112 shuts signal 302 off and the MS 303 is notified that the synchronization is complete. MS 303 sets its output frequency to the Generator frequency and locks it. Now, the Generator 106 and Inverter 111 work synchronously.

At time t_3, TSC 112 produces a signal 116 that forces transfer switch 104 toggling to generator 106. When transfer switch 104 has been configured into its correct position (t_4), SSC 308 generates signals 309 and 310 that return both Static Switches 108 and 110 into their initial position: SS 108 is on and SS 110 is off. The load 109 is uncoupled from DC/AC inverter 111 and is now coupled to generator 106 via transfer switch 104. The inverter 111 becomes idle again.

The method of re-transferring the load 109 from generator 106 to utility source 101 occurs in a similar fashion. When utility source 101 begins to produce an input signal 311 that is within the deviation range, TSC 112 sends the acknowledgement signal 305 to SSC 308. In response, SSC 308 sends signals 309 and 310 to turn static switch 108 “off” and static switch 110 “on”, causing a source-transfer from generator 106 to DC/AC inverter 111. Further, TSC 112 sends a signal 302 “Start Synchronization” to MS 303. Receiving this signal, the MS 303 sets its output frequency off by 0.5Hz to the Utility source frequency. As explained above, the frequency difference of 0.5Hz can vary based on the application for which overpass controller 301 and TSC 112 are being used. For example, in residential power systems, the power lines typically have frequency of about 60 ±0.5Hz. In such a scenario (in which the contemplated system is being used in a residential and/or industrial power system), the frequency difference will be set to about 0.5Hz.

The frequency difference allows synchronizing between Inverter 111 to Utility source 101 within 1 second. As soon as synchronization is achieved, the TSC 112 stops sending signal 302, notifying MS 303 that the synchronization is complete. MS 303 sets its output frequency to the frequency of the utility source 101 and locks it. Now, the utility source 101 and inverter 111 work synchronously. The TSC 112 then toggles transfer switch 104 by sending a signal 116. When the transfer is complete, TSC 112 sends signal 305 to SSC 308. In response to this signal, SSC 308 toggles static switch 108 to be "on", and static switch 110 to be "off," which re-connects load 109 to utility source 101. The re-transfer from generator 106 to utility source 101 is now complete.

Figure 5 illustrates another three-phase source-transfer system 500 that may be used in accordance with exemplary embodiments. As shown in Figure 5, devices such as static switches 108 and 109, inverter 111, comparator 306 and master synchronizer 303 have a three-channel arrangement and appropriate three-wire connections. The SSC 308 makes a decision on load transfer based on analyzing each individual channel sensing.

Figure 6 is a flowchart depicting a method of ensuring that load 109 receives an uninterrupted supply of power in accordance with an exemplary embodiment. Although described below as being carried out by a processor (not shown) in overpass controller 301, it should be understood that the processor may be situated in TSC 112, and/or in a component controlling TSC 112, and overpass controller 301. In addition, the processor may be communicatively coupled to a memory storage (not shown) in overpass controller 301. The memory storage may store instructions that the processor can use. As one example, the processor may use signals from MS 303, comparator 306, SSC 308, TSC 112, inverter 111, and the instructions stored in memory storage to carry out the steps shown in Figure 6.

At block 601, a processor makes a determination of whether load 109 is powered either by utility source 101 or generator 106. If the processor determines that load 109 is powered by utility source 101, then the processor at block 602 determines whether the magnitude of voltage 311 from utility source 101 is within an acceptable deviation range of signal 304.

At block 602, if the determination is that the instantaneous value of signal 311 is within an acceptable deviation range of signal 304, then at block 603, the processor ensures that the DC/AC inverter 111 is idle. In one embodiment, the processor instructs SSC 308 to send signals 309 and 310. Signal 309 turns static switch 108 on. And signal 310 turns static switch 110 off. In this condition, DC/AC inverter 111 is idle. Typically, this condition is maintained until the processor detects that magnitude or the instantaneous value of signal 311 is not within a sufficient or acceptable deviation range of signal 304.

Alternatively, if the processor determines at block 602 that magnitude or the instantaneous value of signal 311 is not within a sufficient or acceptable deviation range of signal 304, the processor at block 604 ensures that DC/AC inverter 111 is active. In one embodiment, the processor at block 604, turns off static switch 108 of and turns static switch 110 on. In this condition, inverter 111 is active.

At block 605, the processor determines whether source 101 has failed for longer than ¼ of a cycle (by RMS computation). If the determination is that source has not failed for at least ¼ of a cycle, then the processor returns to block 602. On the other hand, if the processor, at block 605, determines that the source has failed for longer than ¼ of a cycle, then processor sends signal 107 to generator 106. At block 606, generator 106 is signaled to turn on.

At block 607, the processor makes a determination of whether the voltage from generator 106 has been stabilized. In one embodiment, generator 106 takes about 15-20 seconds to stabilize. Once the voltage from generator 106 has stabilized, the processor, at block 608, begins a synchronization process between the DC/AC inverter 111 and generator 106. This synchronization process ensures that the voltage from generator 106 is in phase with the voltage from DC/AC inverter 111.

At block 609, the processor commands TSC 112 to send a signal 116 to toggle transfer switch 104 so that generator 106 is connected to load 109.

At block 610, once the transfer switch 104 has toggled in to an “emergency position” so that generator 106 is coupled to load 109, the processor commands SSC 308 to turn on static switch 108 and turn off static switch 110. In this condition, DC/AC inverter 111 is idle.

Returning to block 601, in the event that load 109 is powered by generator 106, the processor makes a determination at block 611 of whether utility source 101 is available. If the determination is that the utility source 101 is not available, then the processor ensures that static switch 108 is on and static switch 110 is off, in which case, the DC/AC inverter 111 is idle. Alternatively, if the determination at block 611 is that the normal utility 101 is available, then the processor, at block 613, instruct SSC 308 to turn off static switch 108 and turn on static switch 110. In this condition, DC/AC inverter 111 is active. Once the DC/AC inverter 111 is active, inverter 111 and utility source 101 are synchronized at block 614. In on embodiment, the phase and frequency of the signal from DC/AC inverter 111 is synchronized with the phase and frequency of utility source 101. Once the two signals have been synchronized, at block 615, the processor sends a stop signal to generator 106 and toggles transfer switch 104 to its normal position so that now load 109 is connected to utility source 101.

Figure 7 is a state diagram, illustrating the different states of a source transfer system. When a source is available, every zero crossing of the available source voltage initiates a half-wave generation (transition from State 1 to State 2 and vice versa). At every zero crossing, MS 303 starts a timer and resets it when the next zero crossing occurs. Before resetting the timer, MS 303 stores the new timer value T_{NEW} (which represents the last half wave duration). This new parameter is used for the next half cycle of sine wave generation. Therefore, every next half cycle is created according to the stored time value. If the cycle length of the source voltage changes, the very next half cycle is adjusted accordingly. When the source fails, the overpass controller 301 transfers the load to inverter 111. In such a condition, MS 303 transitions to either State 3 or 4. In either of these states, the sensing of the source voltage stops. Thus, the very next half wave and all following cycles will have the frequency of the last known frequency of the available source. The signal 302 "Start Synchronization" forces MS 303 into State 5. In this state, the MS 303 sets its frequency off by 0.5 Hz to the frequency of available power source. The active phase synchronization between MS 303 (Inverter) and available source begins as it was described above. As soon as synchronization has been completed, MS 303 transitions into State 6. In this state, the MS 303 set its output frequency to the frequency of available source. When power transfer has been completed, the MS 303 returns to the initial State 1.

Exemplary embodiments of the present invention have been described above. Those skilled in the art will understand, however, that changes and modifications may be made to the embodiments described without departing from the true scope and spirit of the present invention, which is defined by the claims.

CLAIMS

1. A method comprising:

receiving a sinusoidal input signal from a first power source;

generating a sinusoidal output signal having a magnitude that defines a lower limit of a deviation range over which the sinusoidal input signal can deviate before initiating a source-transfer from the first power source to a second power source;

comparing an input signal instantaneous value with an output signal’s instantaneous value; and

detecting that the input signal instantaneous value has fallen below the lower limit of the deviation range, and in response, sending a digital signal to a switch controller, the digital signal causing the load to be coupled to the second power source.

2. The method of claim 1, wherein the sinusoidal output signal has the same phase and frequency as the sinusoidal input signal.

3. The method of claim 1, wherein generating a sinusoidal output signal further comprises:

superimposing the sinusoidal input signal on the sinusoidal output signal so that the sinusoidal output signal has a smaller amplitude than the amplitude of the sinusoidal input signal.

4. The method of claim 3, wherein the sinusoidal output signal has an amplitude that is approximately 15% smaller than the nominal value of the sinusoidal input signal.

5. The method of claim 1, wherein detecting that the input signal instantaneous value has fallen below the lower limit of the deviation range, and in response, sending a digital signal to a switch controller, comprises not waiting for a ¼ of a cycle before sending the switch control signal to the switch controller.

6. The method of claim 1, wherein the second power source provides power to the load instantaneously and does not need to be stabilized.

7. The method of claim 6, wherein the second power source is a DC/AC inverter, which functions as a temporary power source for the load, and in which the DC/AC inverter is connected to DC energy storage.

8. The method of claim 1, wherein the step of sending the digital signal to a switch controller, the digital signal causing the load to be coupled to the second power source, further comprises: (i) sending a first control signal to a first static switch, the first static switch in between the load and the first power source and (ii) sending a second control signal to a second static switch, the second static switch in between the load and the second power source.

9. The method of claim 8, wherein (i) sending the first control signal to the first static switch opens the first static switch, thereby disconnecting the load with the first power source and (ii) sending the second control signal to the second static switch turn the second static switch on, thereby coupling the load with the second power source.

10. The method of claim 9, wherein the step of coupling the load to the second power source occurs after the load is disconnected from first power source.

11. The method of claim 10, where in disconnecting the load from the first power source and then coupling the load to the second source causes the load to be un-powered for at least 1/400 of a cycle.

12. The method as in claim 1, further comprising:

detecting that the input voltage signal sags below the output voltage signal for at least ¼ of a cycle, and in response:

sending a start-signal to a power generator, which generates a sinusoidal generator signal;

waiting for the power generator to stabilize;

synchronizing the power generator with the second power source;

connecting the load to the power generator; and

after the load has connected to the load generator, disconnecting the load from the second power source.

13. The method of claim 12, wherein before synchronizing the power generator with the second power source, the sinusoidal output signal has a first frequency and the sinusoidal generator signal has as second frequency.

14. The method of claim 13, wherein synchronizing the generator with the second power source comprises setting the first frequency and the second frequency to have a

difference of 0.5 Hz, which allows the second power source to be synchronized to the generator within at least one second.

15. An apparatus comprising:

a synchronizer coupled to a first power source receiving a sinusoidal input signal, the synchronizer generating a sinusoidal output signal, the sinusoidal output signal having a magnitude that is preset according to a ratio of the nominal value of the sinusoidal input signal;

a comparator receiving the sinusoidal input signal from the first power source and the sinusoidal output signal from the synchronizer, the comparator comparing the instantaneous values of the sinusoidal input signal from the first power source and the sinusoidal output signal; and

a static switch controller connected to the comparator, the static switch controller operable to couple a load to a second power source in response to a condition that the instantaneous voltage of the sinusoidal input signal is less than the instantaneous voltage of the sinusoidal output signal.

16. The apparatus of claim 15, wherein the comparator functions to send a digital signal to the static switch controller in response to detecting that the instantaneous voltage of the sinusoidal input signal is less than the instantaneous voltage of the sinusoidal output signal.

17. The apparatus of claim 15, wherein the synchronizer is coupled to a transfer switch controller (TSC) in which the TSC functions to compute root mean square values of the sinusoidal input signal, the TSC sending a synchronization signal that synchronizes synchronizer with a third source.

18. The apparatus of claim 17, wherein the third source is a back up generator that needs to be stabilized before the TSC can send a synchronization signal.

19. The apparatus of claim 15, wherein the second power source provides power to the load instantaneously and does not need to be stabilized.

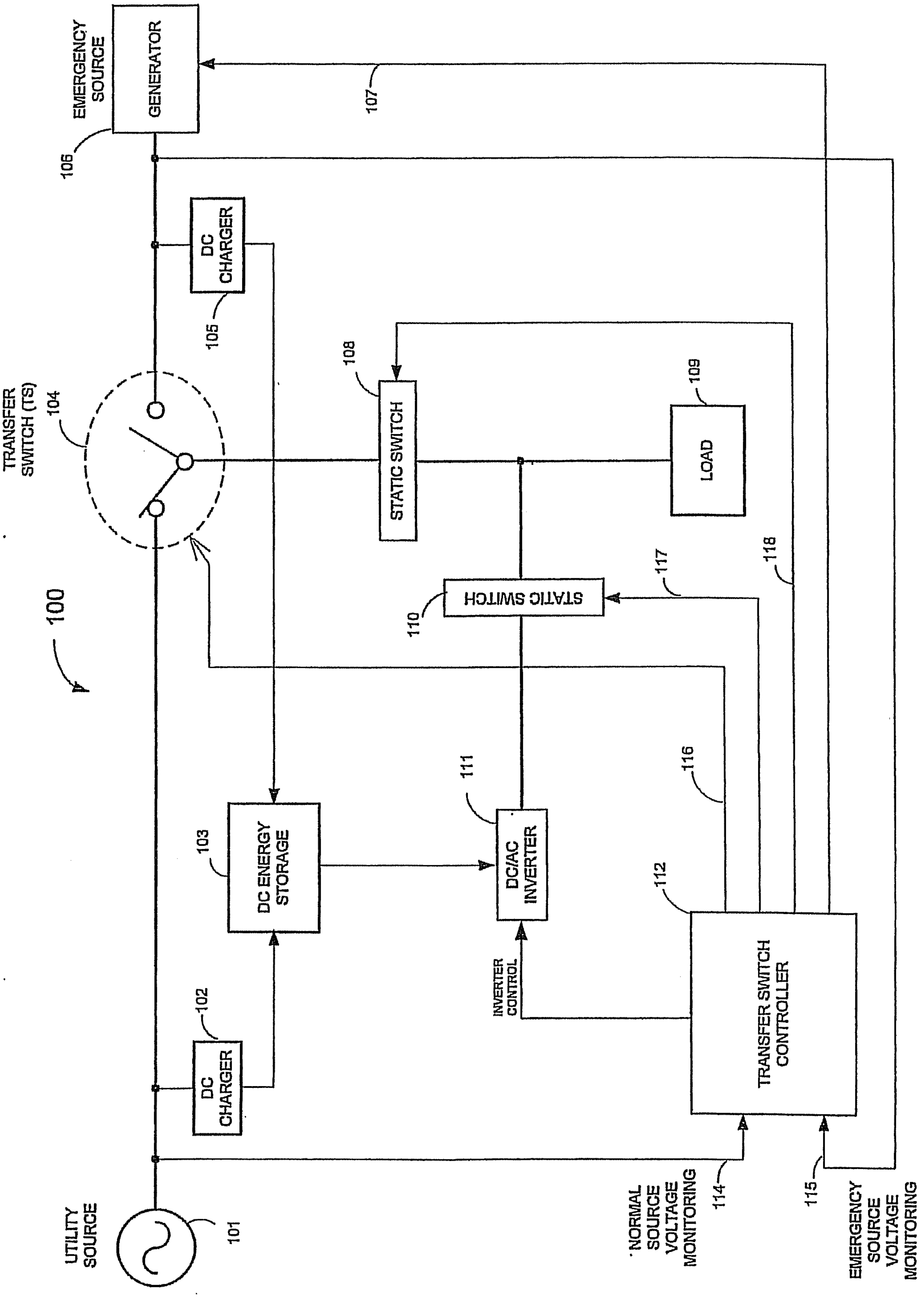
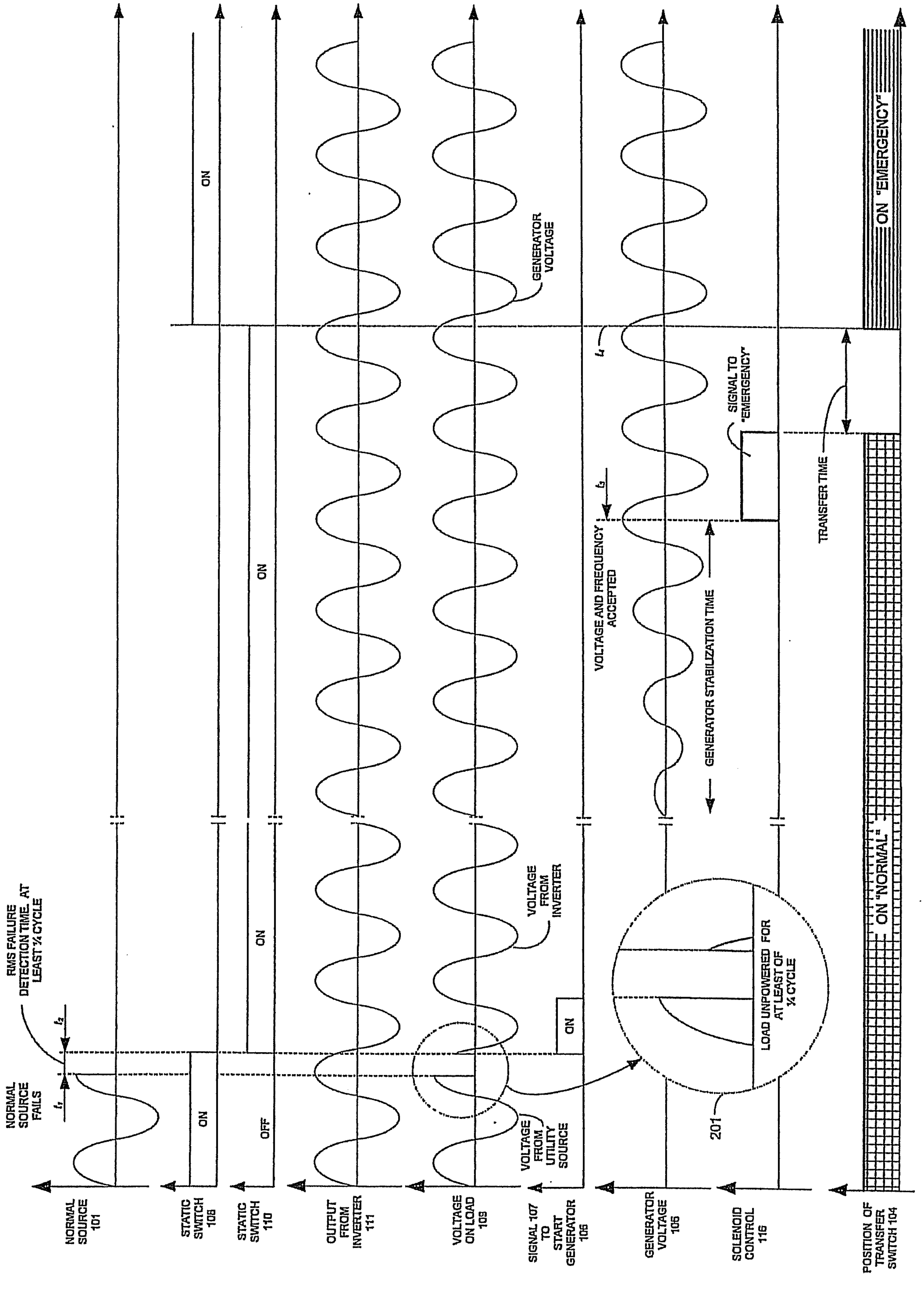


FIGURE 1 PRIOR ART


NORMAL SOURCE 101
STATIC SWITCH 108
STATIC SWITCH 110
OUTPUT FROM INVERTER 111
VOLTAGE ON LOAD 109
SIGNAL 107 TO START GENERATOR 106
GENERATOR VOLTAGE 106
SOLENOID CONTROL 116
POSITION OF TRANSFER SWITCH 104
NORMAL SOURCE FAILS
t_1
RMS FAILURE DETECTION TIME, AT LEAST ¼ CYCLE
t_2
ON
OFF
ON
ON
ON
ON
ON
VOLTAGE FROM UTILITY SOURCE
VOLTAGE FROM INVERTER
GENERATOR VOLTAGE
201
LOAD UNPOWERED FOR AT LEAST OF ¼ CYCLE
GENERATOR STABILIZATION TIME
VOLTAGE AND FREQUENCY ACCEPTED
t_3
t_4
SIGNAL TO "EMERGENCY"
TRANSFER TIME
ON "NORMAL"
ON "EMERGENCY"

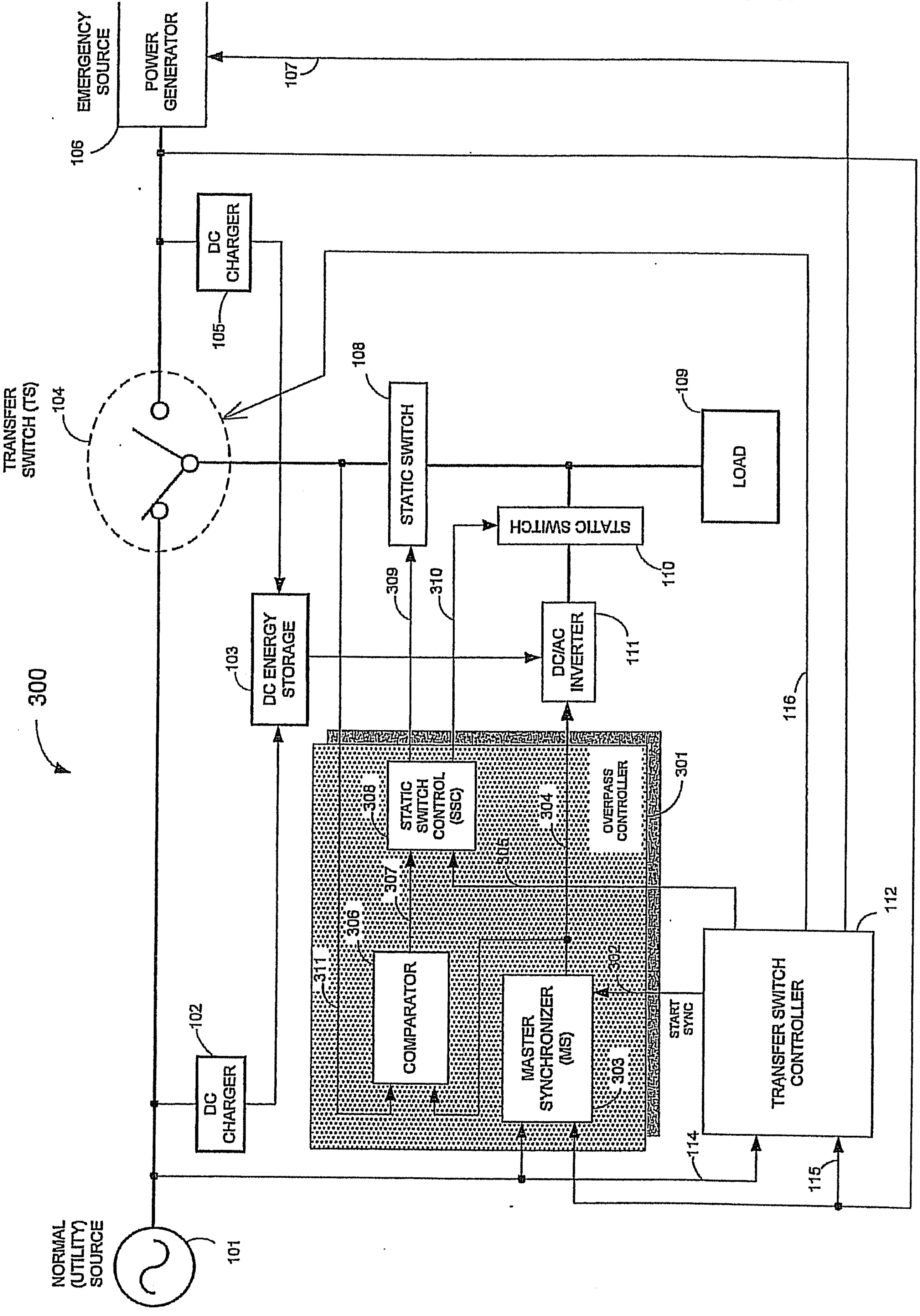

300
NORMAL (UTILITY) SOURCE
101
DC CHARGER
102
DC ENERGY STORAGE
103
TRANSFER SWITCH (TS)
104
DC CHARGER
105
EMERGENCY SOURCE
POWER GENERATOR
106
107
STATIC SWITCH
108
LOAD
109
STATIC SWITCH
110
DC/AC INVERTER
111
TRANSFER SWITCH CONTROLLER
112
114
115
116
OVERPASS CONTROLLER
301
302
START SYNC
MASTER SYNCHRONIZER (MS)
303
304
305
COMPARATOR
306
307
STATIC SWITCH CONTROL (SSC)
308
309
310
311

FIGURE 3

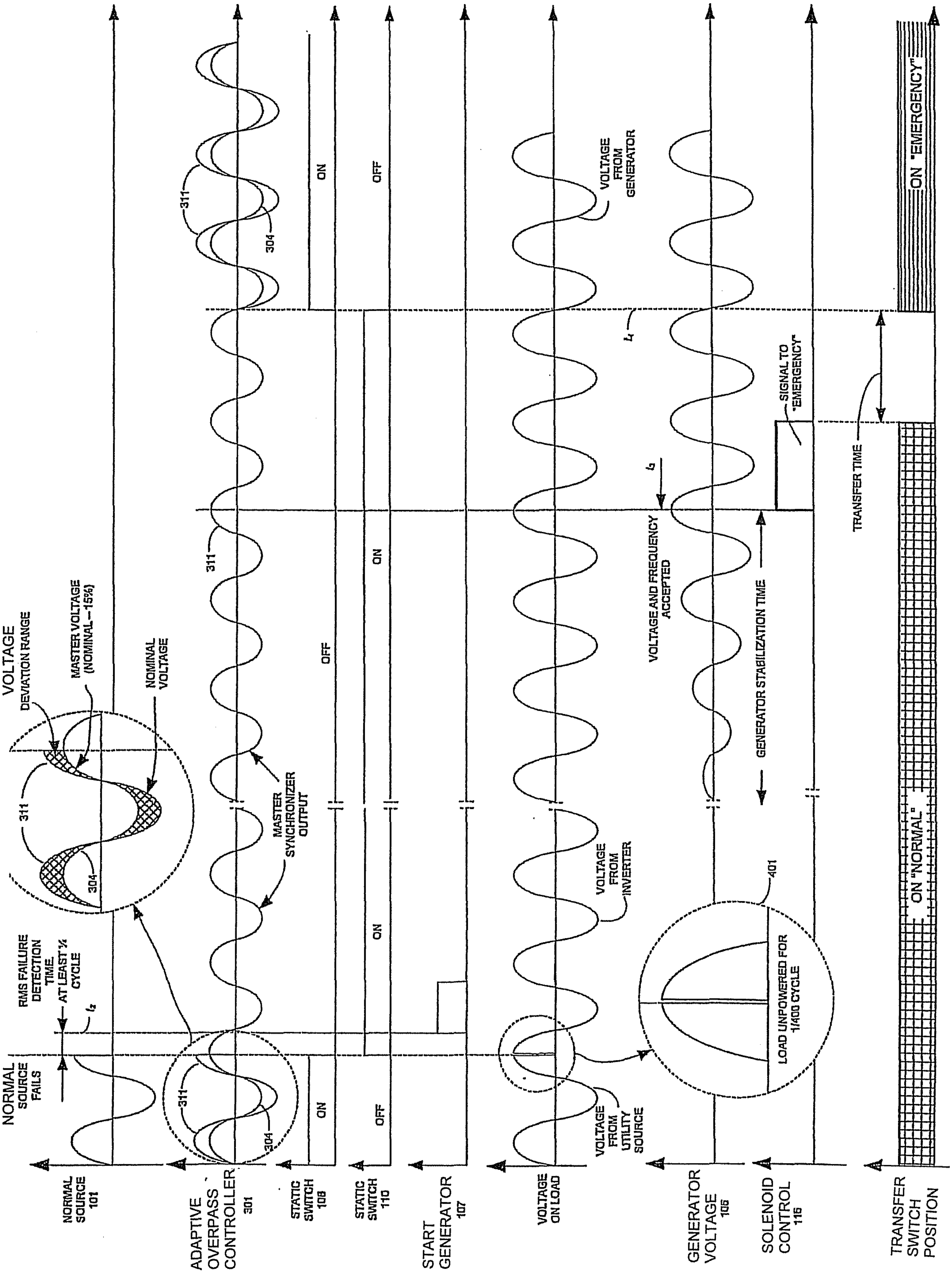


FIG. 4 SUGGESTED LOAD TRANSFER FROM NORMAL TO EMERGENCY SOURCE

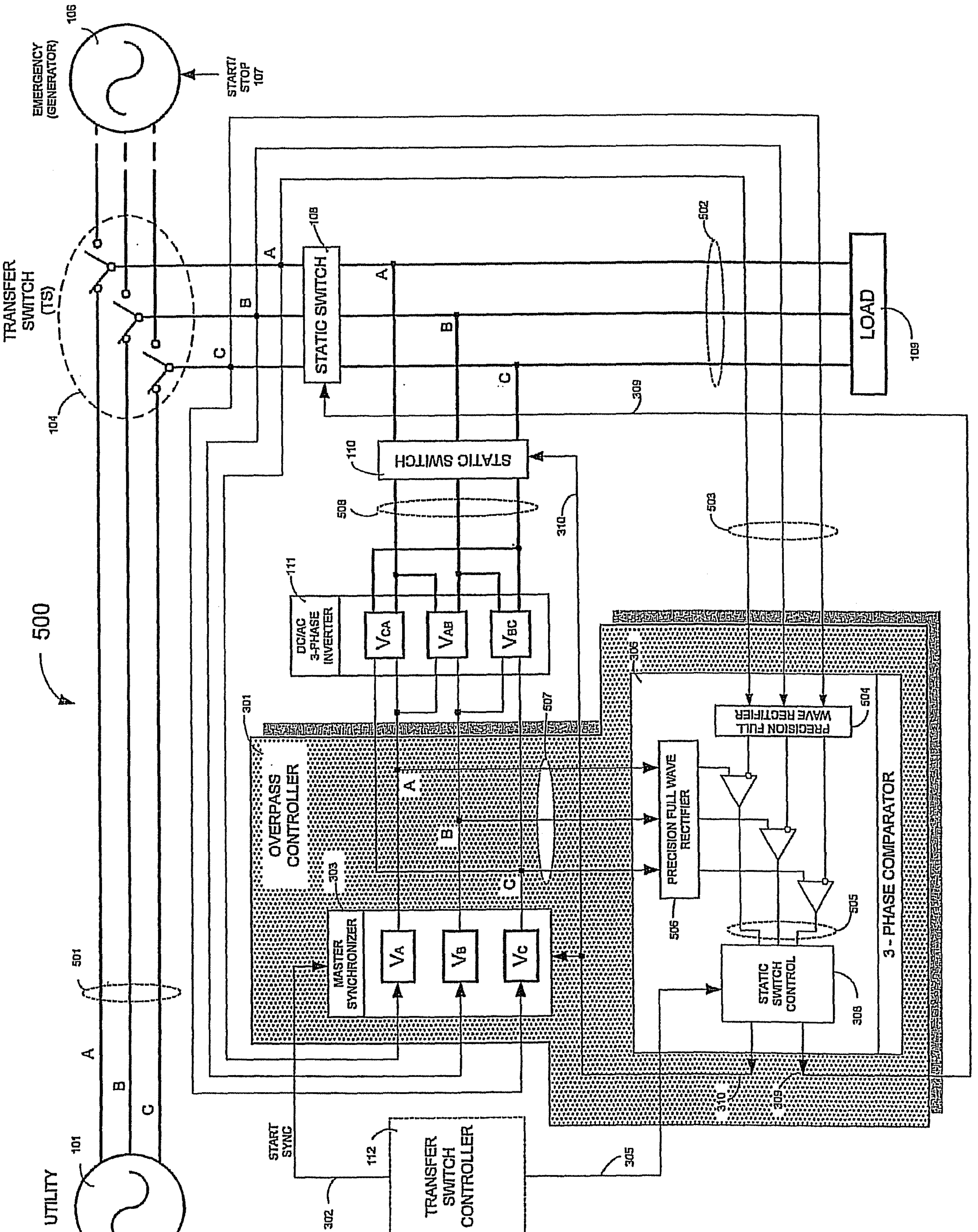

500
UTILITY
101
A
B
C
501
EMERGENCY (GENERATOR)
106
START/ STOP 107
TRANSFER SWITCH (TS)
104
STATIC SWITCH
108
LOAD
109
502
309
STATIC SWITCH
110
508
310
503
DC/AC 3-PHASE INVERTER
111
V_{CA}
V_{AB}
V_{BC}
301
OVERPASS CONTROLLER
MASTER SYNCHRONIZER
303
V_A
V_B
V_C
507
306
PRECISION FULL WAVE RECTIFIER
504
PRECISION FULL WAVE RECTIFIER
506
505
STATIC SWITCH CONTROL
308
3 - PHASE COMPARATOR
310
309
START SYNC
302
112
TRANSFER SWITCH CONTROLLER
305

FIG. 5

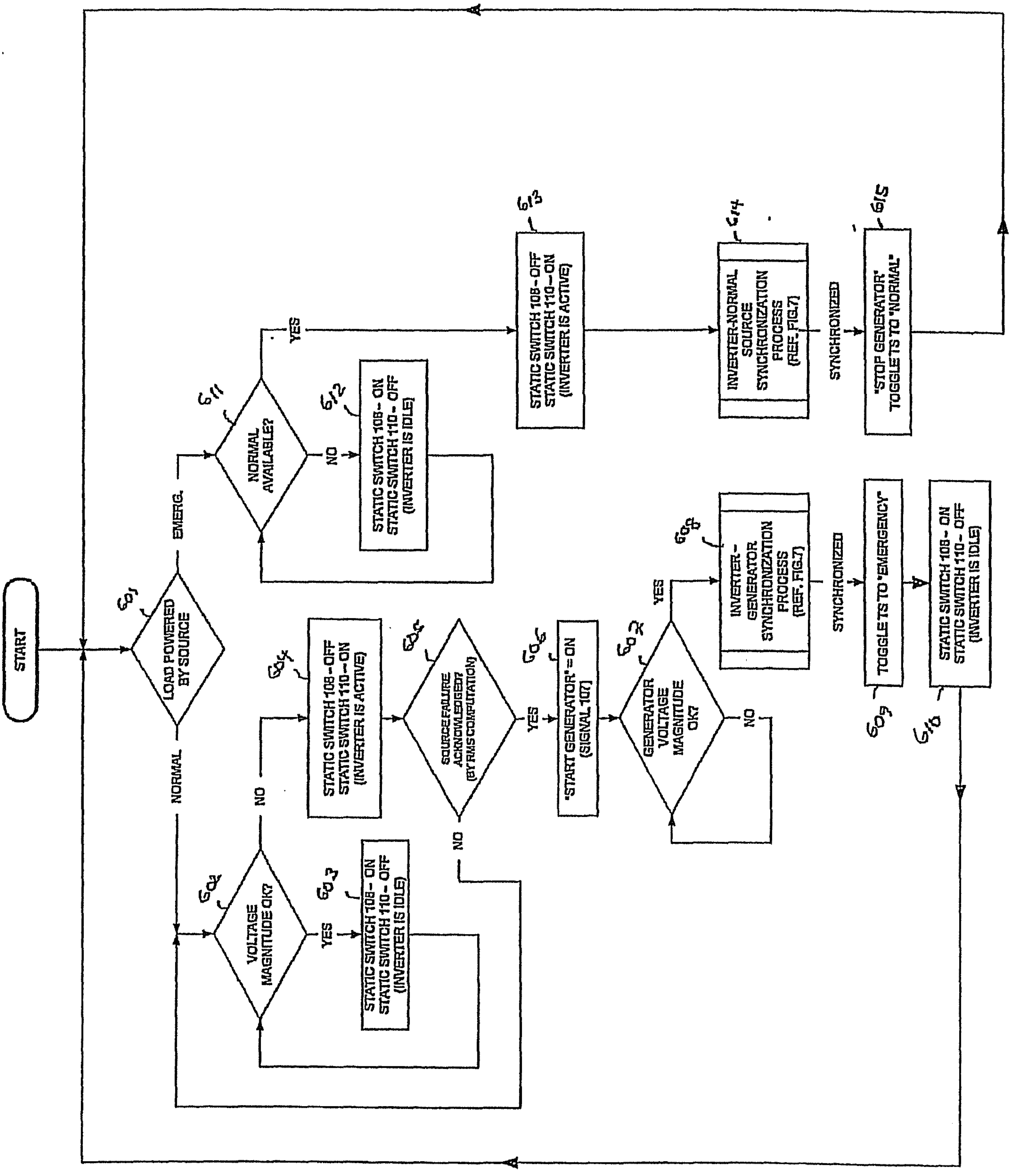

START
LOAD POWERED BY SOURCE
601
NORMAL
EMERG.
VOLTAGE MAGNITUDE OK?
602
YES
NO
STATIC SWITCH 108 - ON
STATIC SWITCH 110 - OFF
(INVERTER IS IDLE)
603
STATIC SWITCH 108 - OFF
STATIC SWITCH 110 - ON
(INVERTER IS ACTIVE)
604
SOURCE FAILURE ACKNOWLEDGED? (BY RMS COMPUTATION)
605
YES
NO
"START GENERATOR" = ON (SIGNAL 107)
606
GENERATOR VOLTAGE MAGNITUDE OK?
607
YES
NO
INVERTER - GENERATOR SYNCHRONIZATION PROCESS (REF. FIG.7)
608
SYNCHRONIZED
TOGGLE TS TO "EMERGENCY"
609
STATIC SWITCH 108 - ON
STATIC SWITCH 110 - OFF
(INVERTER IS IDLE)
610
NORMAL AVAILABLE?
611
NO
YES
STATIC SWITCH 108 - ON
STATIC SWITCH 110 - OFF
(INVERTER IS IDLE)
612
STATIC SWITCH 108 - OFF
STATIC SWITCH 110 - ON
(INVERTER IS ACTIVE)
613
INVERTER-NORMAL SOURCE SYNCHRONIZATION PROCESS (REF. FIG.7)
614
SYNCHRONIZED
"STOP GENERATOR" TOGGLE TS TO "NORMAL"
615

FIG. 6

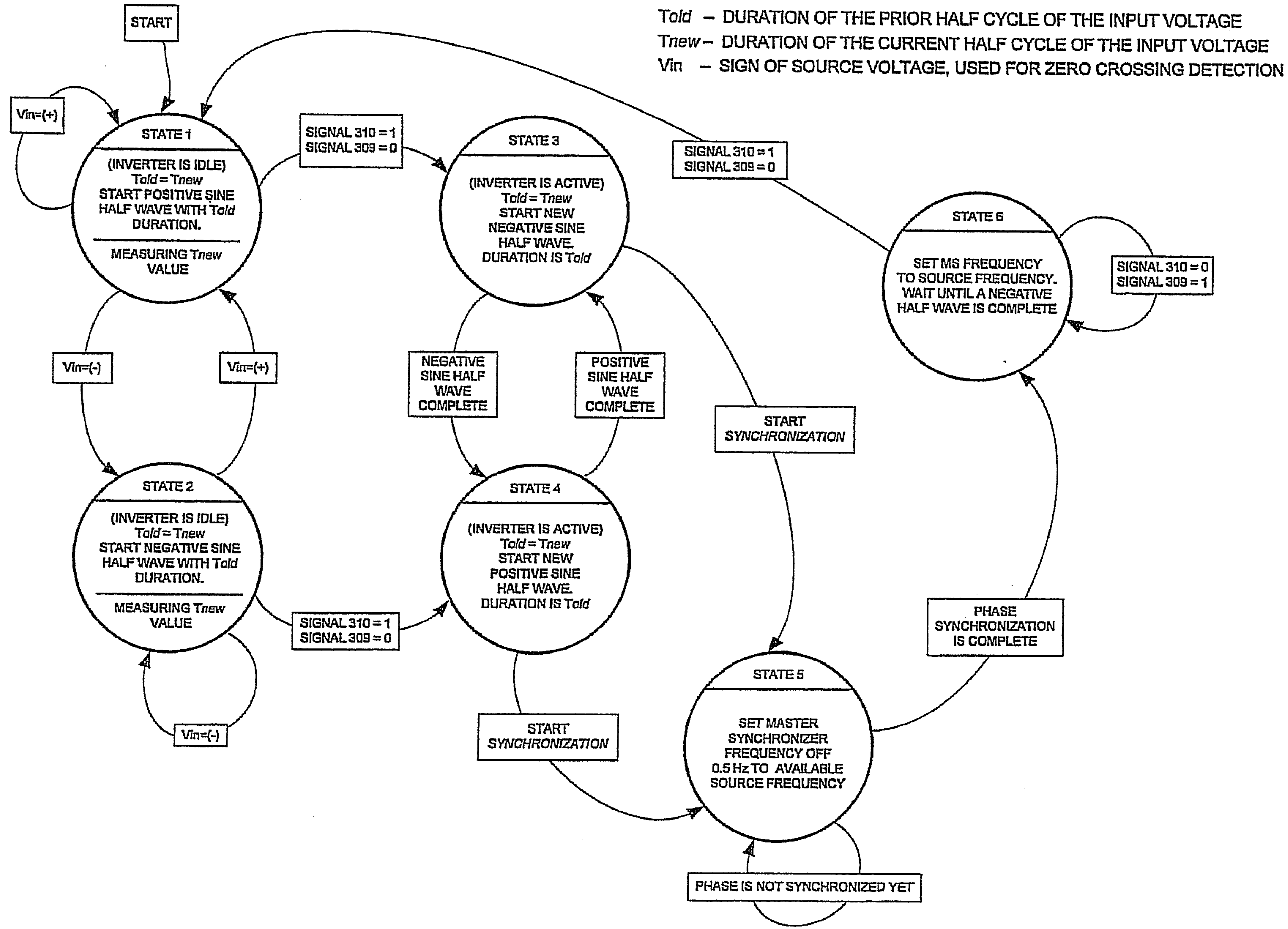

Told – DURATION OF THE PRIOR HALF CYCLE OF THE INPUT VOLTAGE
Tnew – DURATION OF THE CURRENT HALF CYCLE OF THE INPUT VOLTAGE
Vin – SIGN OF SOURCE VOLTAGE, USED FOR ZERO CROSSING DETECTION
START
Vin=(+)
STATE 1
(INVERTER IS IDLE) Told = Tnew START POSITIVE SINE HALF WAVE WITH Told DURATION.
MEASURING Tnew VALUE
SIGNAL 310 = 1 SIGNAL 309 = 0
STATE 3
(INVERTER IS ACTIVE) Told = Tnew START NEW NEGATIVE SINE HALF WAVE. DURATION IS Told
SIGNAL 310 = 1 SIGNAL 309 = 0
STATE 6
SET MS FREQUENCY TO SOURCE FREQUENCY. WAIT UNTIL A NEGATIVE HALF WAVE IS COMPLETE
SIGNAL 310 = 0 SIGNAL 309 = 1
Vin=(-)
Vin=(+)
NEGATIVE SINE HALF WAVE COMPLETE
POSITIVE SINE HALF WAVE COMPLETE
START SYNCHRONIZATION
STATE 2
(INVERTER IS IDLE) Told = Tnew START NEGATIVE SINE HALF WAVE WITH Told DURATION.
MEASURING Tnew VALUE
SIGNAL 310 = 1 SIGNAL 309 = 0
STATE 4
(INVERTER IS ACTIVE) Told = Tnew START NEW POSITIVE SINE HALF WAVE. DURATION IS Told
PHASE SYNCHRONIZATION IS COMPLETE
Vin=(-)
START SYNCHRONIZATION
STATE 5
SET MASTER SYNCHRONIZER FREQUENCY OFF 0.5 Hz TO AVAILABLE SOURCE FREQUENCY
PHASE IS NOT SYNCHRONIZED YET

FIG. 7