

METHODS AND APPARATUS FOR ADAPTIVE OPERATION OF SOLAR POWER SYSTEMS

TECHNICAL FIELD

5 Generally, the inventive technology relates to adaptively operating a solar power system. More particularly, the inventive technology may involve dynamically adjusting voltage output limits within the system to achieve desired operating voltages. The inventive technology may be particularly suited to adapting system operation to changing conditions or unforeseen events.

BACKGROUND

10 While solar power is a promising source of renewable energy, significant challenges remain with respect to exploiting this technology. One such challenge may involve a susceptibility of solar power systems to be influenced by a wide range of operating conditions. This susceptibility in part may stem from the architecture by which solar power systems typically are designed. In particular, solar power systems generally may utilize a distributed architecture, wherein a relatively large number of individual solar sources – such as solar panels – are used to generate power from sunlight. While ultimately the output of these individual solar sources may be combined to produce the overall power put out by the system, nevertheless each individual solar source may operate within its own set of conditions apart from the other solar sources in the system.

20 Several factors may influence the conditions within which individual solar sources operate. These conditions may include temperature, insolation, the photoelectric characteristics of the solar source itself, and the like. Moreover, individual solar sources frequently are operated with the goal of obtaining the maximum possible power output from the source. Techniques for operating an individual solar source in this manner generally may be referred to as maximum power point tracking (MPPT), and may be described in some embodiments for example in U.S. Patent Application No. 12/363,709, Filed January 30, 2009, entitled “Systems for Highly Efficient Solar Power Conversion”; International Patent Application No. PCT/US08/80794, filed October 22, 2008, entitled “High Reliability Power Systems and Solar Power Converters”; International Patent

Application No. PCT/US08/79605, filed October 10, 2008, entitled “Novel Solar Power Circuits and Powering Methods”; International Patent Application No. PCT/US08/70506, filed July 18, 2008, entitled “High Efficiency Remotely Controllable Solar Energy System”; International Patent Application No. PCT/US08/60345, filed April 15, 2008,
5 entitled “AC Power Systems for Renewable Electrical Energy”; and International Patent Application No. PCT/US08/57105, filed March 14, 2008, entitled “Systems for Highly Efficient Solar Power”; each hereby incorporated by reference herein in its entirety. As a result of these factors, each solar source in a solar power system may operate within a set of conditions perhaps unique and different from the other solar sources in the system.

10 Because a typical solar power system may have a large number of individual solar sources, each operating essentially within its own conditional framework, the task of combining the voltage outputs of these various solar sources to achieve a consistent and efficient operating voltage of the solar power system may pose technical challenges. For example, the solar sources in a solar power system often may be interconnected in
15 various serial and parallel structures, such as wherein a number of individual solar panels may be serially connected to form a string, and wherein a number of strings may be connected in parallel to form an array. Naturally, the electrical properties of such serial and parallel connections may affect how the voltage output of individual solar sources is combined with the operating voltage of the overall system.

20 At one extreme, for example, underperforming solar sources on an individual string may cause a voltage drop in the string as a whole, since the total voltage in the string merely is the sum of the voltages of the individual solar sources on the string due to the serial nature of their interconnection. If the voltage in the string drops below a certain level, this may cause a loss of power for the array of strings connected in parallel,
25 due to their parallel interconnection.

At another extreme, spikes in the output of individual solar sources in a string may cause a voltage gain for the string as whole, which again may result in inefficiencies due to the connection topology. Such spikes in voltage may be undesirable for efficiency, safety, or regulatory reasons. For example, solar power systems often are
30 subject to regulatory requirements that impose a maximum operating voltage for the

system – frequently a limit of 600 volts – and spikes in the voltage output of individual solar sources can cause the total voltage in the system to exceed the regulatory limit.

To deal with technical issues of this nature, conventional solar power systems may utilize techniques to limit the voltage output of solar sources. For example, where a solar source is known to put out a certain voltage under normal conditions, limits may be designed to create an operating range encompassing both the source's expected normal output as well as a degree of variance to accommodate changes in operating conditions. One architecture for setting such limits may involve connecting each solar source to a photovoltaic DC-DC power converter, wherein the converter may have hardware or software that sets voltage output limits within which the solar source is permitted to operate, and wherein the converters may be serially connected to form a string. The voltage output limits may provide a voltage output range within which the solar source may operate that can accommodate a degree of changed conditions. Should the voltage output limits be exceeded, the solar source may be shut down, disengaged, or otherwise controlled within the solar power system.

However, conventional voltage output limits for solar sources may entail significant drawbacks. For example, conventional voltage output limits only may be capable of being statically set. Once set, the voltage output limits may not be able to be adjusted in real time with respect to changing conditions affecting the solar power system. As a result, setting conventional voltage output limits in this manner may have resulted in undesirable trade-offs. For example, one trade-off may be to foreclose circumstances where it may be desirable to put out voltage for an individual solar source beyond the limit set for its output, such as perhaps to offset unusual voltage drops elsewhere in the system.

The foregoing problems related to conventional solar power systems may represent a long-felt need for an effective solution to the same. While implementing elements may have been available, actual attempts to meet this need may have been lacking to some degree. This may have been due to a failure of those having ordinary skill in the art to fully appreciate or understand the nature of the problems and challenges involved. As a result of this lack of understanding, attempts to meet these long-felt needs may have failed to effectively solve one or more of the problems or challenges here

identified. These attempts may even have led away from the technical directions taken by the present inventive technology and may even result in the achievements of the present inventive technology being considered to some degree an unexpected result of the approach taken by some in the field.

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SUMMARY DISCLOSURE OF THE INVENTION

The inventive technology relates to methods and apparatus for adaptive operation of solar power systems and in embodiments may include the following the features: techniques for providing one or more external state parameters to a photovoltaic DC-DC power converter; techniques for relationally setting a dynamically adjustable voltage output limit for a photovoltaic DC-DC power converter in relation to one or more external state parameters; and techniques for utilizing a dynamically adjustable voltage output limit of a photovoltaic DC-DC power converter to convert DC photovoltaic input. Accordingly, the objects of the methods and apparatus for adaptive operation of solar power systems described herein address each of the foregoing in a practical manner. Naturally, further objects of the inventive technology will become apparent from the description and drawings below.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic representation of a single solar source of a solar power system in one embodiment.

Fig. 2 is a schematic representation of multiple solar sources interconnected in serial and parallel arrangements in a solar power system in one embodiment.

Fig. 3 is a plot of a relationship for current and voltage for a given solar source in one embodiment.

Fig. 4 is a plot of a relationship for power and voltage for a given solar source in one embodiment.

Figs. 5a and 5b are plots of conventional power converter response incorporating static limits to changing operating conditions for a given power converter in one embodiment.

Figs. 6a and 6b are plots of power converter response utilizing dynamically adjustable voltage output limits in response to changing operating conditions for a given power converter in one embodiment.

Figs. 7a, 7b, and 7c are schematic representations of conventional string response incorporating static limits to changing operating conditions for a given string in one embodiment.

Figs. 8a, 8b, and 8c are schematic representations of string response utilizing dynamically adjustable voltage output limits in response to changing operating conditions for a given string in one embodiment.

MODES FOR CARRYING OUT THE INVENTION

As mentioned earlier, the present inventive technology includes a variety of aspects, which may be combined in different ways. The following descriptions are provided to list elements and describe some of the embodiments of the present inventive technology. These elements are listed with initial embodiments, however it should be understood that they may be combined in any manner and in any number to create additional embodiments. The variously described examples and preferred embodiments should not be construed to limit the present inventive technology to only the explicitly described systems, techniques, and applications. Further, this description should be understood to support and encompass descriptions and claims of all the various embodiments, systems, techniques, methods, devices, and applications with any number of the disclosed elements, with each element alone, and also with any and all various permutations and combinations of all elements in this or any subsequent application.

Now with reference primarily to Fig. 1, various embodiments may involve a method of solar energy power conversion. An example of a solar power energy conversion apparatus may be shown for one embodiment of the inventive technology in Fig. 1. A solar energy source (1) may have and be used to create a DC photovoltaic output, as by utilizing appropriate photoelectric effect principles. Any suitable solar energy source (1) may be utilized, such as a solar cell, a plurality of electrically connected solar cells, a plurality of adjacent electrically connected solar cells, a solar

panel, a plurality of electrically connected solar panels, a string (27) of electrically connected solar panels, and the like.

A DC photovoltaic output of a solar energy source (1) in various embodiments may be established as a DC photovoltaic input to a photovoltaic DC-DC power converter (2). The photovoltaic DC-DC power converter (2) may serve to accept power from the DC photovoltaic output and intermediate power transfer between the solar energy source (1) on one side and the solar power system (3) on the other side by converting the DC photovoltaic input in a manner that accommodates the requirements of each. As but one example, the photovoltaic DC-DC power converter (2) may permit a solar energy source (1) to be operated at an MPP value, such as by creating a MPP voltage for the solar energy source. To illustrate this, Fig. 3 provides a plot for a hypothetical solar energy source (1) illustrating that a property of solar energy sources (1) is a relationship between current and voltage when the source is in operation. Since power equals voltage times current, it follows that Fig. 4 represents the power produced by this hypothetical solar energy source (1) over a range of voltages. Fig. 4 dictates that maximum power is produced in the solar energy source (1) when the source is operated at the voltage corresponding to the peak of the curve. A photovoltaic DC-DC power converter (2) may allow the solar energy source (1) to operate at just such a voltage, for example perhaps by using maximum photovoltaic power point converter functionality control circuitry (13) to which a solar energy source (1) may be responsive. These MPP aspects may be more fully discussed for example in U.S. Patent Application No. 12/363,709, Filed January 30, 2009, entitled "Systems for Highly Efficient Solar Power Conversion"; International Patent Application No. PCT/US08/80794, filed October 22, 2008, entitled "High Reliability Power Systems and Solar Power Converters"; International Patent Application No. PCT/US08/79605, filed October 10, 2008, entitled "Novel Solar Power Circuits and Powering Methods"; International Patent Application No. PCT/US08/70506, filed July 18, 2008, entitled "High Efficiency Remotely Controllable Solar Energy System"; International Patent Application No. PCT/US08/60345, filed April 15, 2008, entitled "AC Power Systems for Renewable Electrical Energy"; and International Patent Application No. PCT/US08/57105, filed March 14, 2008, entitled "Systems for Highly Efficient Solar Power"; each hereby incorporated by reference herein in its entirety. Other examples of

how a photovoltaic DC-DC power converter (2) may serve to intermediate power transfer between a solar energy source (1) and a solar power system (3) may be discussed elsewhere herein, including for example converting a DC photovoltaic input with a photovoltaic DC-DC power converter (2) utilizing a dynamically adjustable voltage output limit (8).

With further attention primarily to Fig. 1, a converted DC photovoltaic output of a photovoltaic DC-DC power converter (2) may be established as converted DC photovoltaic input into a DC-AC inverter (4). While not necessary for all embodiments of the inventive technology, the DC-AC inverter (4) if included may serve to accomplish the step of inverting this converted DC photovoltaic input into an inverted AC photovoltaic output, such as a power output that can be used by, for example, a power grid (5). The step of inverting an input should be understood as encompassing and creation of any substantially alternating signal from any substantially unidirectional current flow signal even if that signal is not itself perfectly, or even substantially, steady. A DC-AC inverter (4) of any suitable design consistent with the principles discussed herein may be utilized.

Now referring primarily to Fig. 2, individual solar energy sources (1) may be combined to create a plurality of electrically interconnected sources. Such combinations in various embodiments may be responsive through either series or parallel connections. For example, a serially interconnected plurality of sources may form a string (27), perhaps such as a string (27) of solar panels. An example of parallel interconnection may include connecting strings (27) themselves in parallel, perhaps such as to form an array. Regardless of how a plurality of individual solar energy sources (1) are combined, by either physical or electrical layout, certain sources may be adjacent in that they may be exposed to somewhat similar electrical, mechanical, environmental, or insulative conditions. Naturally, output may be combined for serial interconnections so that their voltages may add whereas their currents may be identical. Conversely, currents may be additive for parallel interconnection whereas voltage may stay constant. Moreover, interconnection may be made in any suitable manner. For example, direct connection is but one manner in which the various elements may be responsive to each other, that is, some effect in one may directly or indirectly cause an effect or change in another.

As shown in Fig. 1, a photovoltaic DC-DC power converter (2) in various embodiments may include an external state data interface (7). The interface may enable the converter to send and receive data regarding operational states of a solar power system (3) external to the converter. Any suitable hardware, software, or the like consistent with the principles discussed herein may be utilized for an external state data interface (7). For example, in some embodiments an external state data interface (7) may send and receive information to and from a central source and enable power converter operation responsive to that central source, such as described for example in International Patent Application No. PCT/US08/70506, filed July 18, 2008, entitled “High Efficiency Remotely Controllable Solar Energy System”, hereby incorporated by reference herein in its entirety. Embodiments also may include an external state data interface (7) configured to send and receive information directly from individual elements within a solar power system (7), such as directly to and from other solar energy sources (1), directly to and from other photovoltaic DC-DC power converters (2), directly to and from other strings (27), or the like. Naturally, system state information may be derived from a variety of conditions. For example, an external state data interface (7) in various embodiments may include a voltage data interface (responsive, for example, to a voltage condition in the system), a current data interface (responsive, for example, to a current condition in the system), a power data interface (responsive, for example, to a power condition in the system), an insolation data interface (responsive, for example, to an insolation condition in the system), a temperature data interface (responsive, for example, to a temperature condition of the system), a system status data interface (responsive, for example, to an operating status of the system), a demand data interface (responsive, for example, to a demand placed on the system), a power converter output data interface (responsive, for example, to the output of one or more other power converters in the system), a string output data interface (responsive, for example, to the output of one or more other strings (27) in the system), a historical data tracking data interface (responsive, for example, to data tracked for an operational history of the system), a regulatory requirement data interface (responsive, for example, to operation of the system within regulatory requirements), or the like.

Moreover, an external state data interface (7) may serve to provide at least one external state parameter to a photovoltaic DC-DC power converter (2), wherein the parameter, of course, may correspond to the information received by the data interface. For example, an external state parameter may be a voltage parameter, a current
5 parameter, a power parameter, an insolation parameter, a temperature parameter, a system status parameter, a demand status parameter, a power converter output parameter, a string output parameter, a historical data tracking parameter, a regulatory requirement parameter, or the like. In various embodiments, an external state data interface and an external state parameter may be multi-parametric, perhaps using two or more parametric
10 components to provide information on an external state of the system. Regardless, an external state parameter may represent data about conditions in a solar power system (3) external to the power converter, which data then may be utilized in the operation of the power converter as may be necessary or desirable.

Such utilization, for example, may involve relationally setting a dynamically
15 adjustable voltage output limit (8) of a photovoltaic DC-DC power converter (2). A voltage output limit (8) may establish a limit on the range of voltages which the converter may be allowed to put out. Figs. 6a and 6b provide one example of voltage output limits (8) specifying maximum voltages which a converter might be limited to. Of course, these examples are merely illustrative and not intended to be limiting.

By being dynamically adjustable, voltage output limits (8) may be capable of
20 being adjusted as a dynamic part of the operation of a solar power system (3), as by way of real-time adjustment, near-real time adjustment, adjustment in equilibrium with other system elements, adjustment to cause an operational effect in the system or in response to an effect caused elsewhere in the system, and so forth. For example, Fig. 6a may show
25 one example in which dynamically adjustable voltage output limits (8) may be maximum voltages which the converter may be allowed to put out, but wherein the value of the maximum may be changed to the values shown in Fig. 6b while the system is in operation, perhaps even as an operational component thereof. Figs. 6a and 6b also may show a dynamically adjustable range (11) for a photovoltaic DC-DC power converter (2).
30 Of course, these examples are merely illustrative and are not intended to be limiting.

Relationally setting a dynamically adjustable voltage output limit (8) may involve setting the limit in relation to the value of one or more criteria, for example in relation to at least one external state parameter. For example, relationally setting a maximum voltage which the converter may put out may involve determining an appropriate maximum value for the voltage in relation to other voltage events in the system. Figs. 6a and 6b provide another example, wherein a dynamically adjustable voltage output limit (8) may be set in relation to a regulatory requirement or regulatory limit (28), creating a dynamically adjustable range (11). Of course, these examples are merely illustrative and not intended to be limiting. Any suitable parameter of the system could be utilized as the basis of relation upon which to relationally set a dynamically adjustable voltage output limit (8).

In various embodiments, a photovoltaic DC-DC power converter (2) may include a dynamically adjustable voltage output limit control (12) to relationally set a dynamically adjustable voltage output limit (8). The control may be relationally responsive to an external state data interface (7), as for example by receiving information from the data interface, operating in response to data interface information, or the like. Any suitable hardware, software, or combination thereof may be used for the control consistent with the principles discussed herein.

Moreover, various embodiments naturally may involve dynamically adjusting a dynamically adjustable voltage output limit (8) responsive to an external state parameter. Figs. 6a and 6b, for example, show an exemplary case in which maximum voltage output limits (8) for a converter have been raised to permit the converter to operate over a wider voltage range, and Figs. 6a and 6b illustrate a dynamically adjustable range (11) for voltage output values. A dynamic adjustment made in this manner of course may be responsive to an external state parameter, for example wherein the external state parameter describes changed conditions in a solar power system (3) making it desirable that a particular converter in question have an expanded or restricted voltage range within which to operate.

Relationally setting and dynamically adjusting voltage output limits (8) may be done for a variety of purposes. One example may involve compensating for an external state parameter. The external state parameter may provide information about a change in

the state of a solar power system (3), and it may be desirable to compensate for the changed condition by operating one or more photovoltaic DC-DC power converters (2) under adjusted voltage output limits (8). An exemplary case of such a situation may involve dropouts of solar energy sources (1) on a string. Figs. 7 and 8 set forth two
5 hypothetical strings (27) experiencing the dropout of multiple solar energy sources (1). For the hypothetical case, presume each source is to put out 40 volts under normal operating conditions. Because each string (27) has 10 sources, each string (27) will produce 400 volts under normal conditions. Further presume the system must operate under a regulatory limit of 600 volts.

10 Figs. 7a, 7b, and 7c present a hypothetical conventional string (27), wherein each converter has static limits set at 50 volts, thereby safeguarding against the possibility of a spike in all 10 converters on the string (27) by ensuring the string (27) can produce only 500 volts at maximum, well below the 600 volt regulatory limit. Under normal operating conditions in Fig. 7a, each source will put out 10 volts and the string (27) will produce
15 400 volts. Under the unusual circumstance of Fig. 7b, where two sources have dropped out, the remaining eight sources may be able to put out 50 volts each, perhaps compensating for the dropouts of the two panels and ensuring the string (27) still produces 400 volts. Under the more dire situation of Fig. 7c, where three sources have dropped out, the string (27) no longer can produce 400 volts, because each of the 7
20 remaining converters would have to put out more than 50 volts, which is above the limit that has been statically set. Consequently, the entire string (27) must drop out in the hypothetical case of Fig. 7c.

By way of comparison, Fig. 8 presents the hypothetical case wherein each power converter has a dynamically adjustable voltage output limit (8). In the normal case of
25 Fig. 8a and the unusual case of Fig. 8b, the results are the same as for the conventional string (27) of Fig. 7. In the dire case of Fig. 8c, however, the string (27) may be kept in operation at 400 volts. This is because the voltage output limits (8) of the remaining seven converters can be dynamically adjusted above 50 volts. More specifically, the voltage output limits (8) of one converter, all converters, or some fraction in between can
30 be adjusted to ensure the string (27) is kept in operation at the desired 400 volts. Naturally, each converter on the string may have an external state data interface (7) by

which the converter is able to receive and act on information regarding the changing voltage conditions in the string (27). For example, voltage output data for individual converters may be provided to a central source in communication with the converters, and the central source may return information enabling individual converters to dynamically adjust their voltage output limits (8) accordingly. In this scenario, each of the seven remaining power converters may receive information from the central source through an external state data interface (7), such that voltage output limits (8) may be raised in a coordinated fashion to compensate for the three dropped out sources. Moreover, prior to raising voltage output limits (8) on the seven remaining converters, it may be desirable to lower the voltage output limits (8) on the three sources which have dropped out. This may serve to guard against voltage spikes in the event the three dropped out sources suddenly come back online (for example where the condition causing the dropout may suddenly abate, such as where insolation levels may suddenly rebound from a shaded state, a blockage may be suddenly removed, an intermittent malfunction may suddenly resolve itself, or the like). Having a lowered voltage output limit (8) already in place for the three dropped out sources may safeguard against an over-voltage risk, such as perhaps overloading an electrical component or exceeding a regulatory voltage requirement, that otherwise might occur should the three dropped out sources suddenly come back online and cause a string voltage which could exceed a regulatory limit. Another change which may occur is the inverter may stop taking power from a solar array. In this case all DC/DC converters may move to their maximum voltage limit. If low producing modules have low voltage limits and high producing modules have high limits it is still possible to always stay below regulatory limits.

Figs. 7 and 8 exemplify one manner in which dynamically adjusting a voltage output limit (8) may compensate for an external state parameter. In various embodiments, an external state parameter compensation control (20), such as of a photovoltaic DC-DC power converter (2), may be utilized to effect such compensation. For example, compensating perhaps may involve raising a voltage output limit (8) of a photovoltaic DC-DC power converter (2), such as with a voltage output limit increase control (21), in response to a voltage drop of the external state parameter, such as detected perhaps by an external state parameter voltage drop detector (22). Conversely,

compensating perhaps may involve lowering a voltage output limit of a photovoltaic DC-DC power converter (2), such as with a voltage output limit decrease control (23), in response to a voltage gain of an external state parameter, such as detected perhaps by an external state parameter voltage gain detector (24). Of course, the foregoing examples
5 are intended to be merely illustrative and should not be construed to limit the scope of the inventive technology.

Relationally setting and dynamically adjusting voltage output limits (8) also may be effected in a variety of manners. As one example, a photovoltaic DC-DC power converter (2) may include a step function control (18). Embodiments may involve
10 implementing a step function to dynamically adjust a dynamically adjustable voltage output limit (8), determining a resultant effect on an external state parameter, and repeating the steps until a desired result is achieved. For example, implementing a step function may involve adjusting a voltage output limit (8) incrementally, discretely, fractionally, or in a likewise manner with respect to an identified endpoint. The precise
15 contours of the steps may be provided by hardware, software, or any other suitable modality. Following each stepwise adjustment, the result on an external state parameter may be observed. In this manner, the adjustment may approach the desired endpoint in a controlled fashion, perhaps avoiding risks such as overshooting the desired target of the adjustment and ensuring the adjustment is approached entirely from one side of the
20 endpoint. As but one example, where it may be critical to avoid exceeding a regulatory voltage limit, utilizing a step function as described may ensure that voltages are raised without risk of exceeding the regulatory requirement.

Another example of how voltage output limits (8) may be relationally set and dynamically adjusted may involve first adjusting an external voltage to a safe condition.
25 A safe condition may be a condition of a solar power system (3) that avoids an undesirable or adverse consequence to the system's operational state, such as perhaps exceeding a regulatory limit for voltage, providing an over-voltage input to an electrical component, or the like. One example of first adjusting an external voltage to a safe state may involve decreasing voltage output limits (8) for one photovoltaic DC-DC power
30 converter (2) prior to raising voltage output limits (8) for another photovoltaic DC-DC power converter (2). In this manner, the risk of exceeding a regulatory voltage limit,

even temporarily, may be reduced or eliminated. Accordingly, a photovoltaic DC-DC power converter (2) in various embodiments may include an external voltage safeguard control (19).

A further example of relationally setting and dynamically adjusting voltage output limits (8) may involve slaving a dynamically adjustable voltage output limit (8) in relation to one or more external state parameters. Slaving may involve setting or adjusting based on criteria, wherein some criteria may take precedence over other criteria. For example, embodiments may involve hierarchically slaving dynamically adjustable voltage output limits (8). Naturally, any hierarchy of criteria may be selected as appropriate consistent with the principles discussed herein. One possible hierarchy may involve first slaving a voltage output limit (8) to a regulatory parameter (for example, to avoid exceeding a regulatory voltage limit), second slaving a voltage output limit (8) to an operational parameter (for example, such as compensating for a voltage drop due to panel dropouts on a string (27)), and third slaving a voltage output limit (8) to an MPP parameter (for example, such as ensuring a solar energy source (1) is operated for MPP). Accordingly, in various embodiments a dynamically adjustable voltage output limit control (12) may be a slaved dynamically adjustable voltage output limit control (12) or even a hierarchically slaved dynamically adjustable voltage output limit control (12). Naturally, such hierarchically slaved controls may include primary slaved controls, secondary slaved controls, tertiary slaved controls, and the like correlated to various hierarchical priorities. For example, a primary control may be a regulatory primary slaved control, a secondary control may be an operational secondary slaved control, a tertiary control may be a MPP tertiary slaved control, and so forth.

Relationally setting and dynamically adjusting voltage output limits (8) also may involve utilizing a set point margin. Such a margin may provide a buffer zone between the maximum voltage output of one or more photovoltaic DC-DC power converters (2) and some absolute value. For example, in some embodiments an absolute value may be a regulatory voltage limit, and a set point margin may provide a buffer zone between the regulatory limit and the maximum output of a plurality of converters operating on a string. If the regulatory voltage limit for a string is 600 volts, for example, a set point margin may be established such that the combined maximum voltage output of all

converters on the string may be 550 volts, thereby leaving a margin of 50 volts as a buffer zone between the converters' output and the regulatory limit. Naturally, establishing the set point margin may be done by relationally setting and dynamically adjusting voltage output limits (8) of photovoltaic DC-DC power converters (2). With reference to Fig. 8, for example, assume hypothetically it may be desirable to achieve a set point of 550 volts and a set point margin of 50 volts below a regulatory voltage limit of 600 volts. With reference to Fig. 8a, the voltage output limit (8) for each converter could be adjusted to 55 volts; with reference to Fig. 8b, the voltage output limit (8) for each converter could be adjusted to 68.75 volts; and with reference to Fig. 8c, the voltage output limit (8) for each converter could be adjusted to 78.5 volts. In each foregoing case, the total output voltage for the string would not exceed 550 volts, leaving a margin of 50 volts below the regulatory limit of 600 volts. Of course, a dynamically adjustable voltage output limit control (12) in this situation may be a set point margin control.

Another example of how voltage output limits (8) may be relationally set and dynamically adjusted may involve relationally setting or dynamically adjusting using a switchmode modality, duty cycle modality, or the like, perhaps for example as discussed in International Patent Application No. PCT/US08/57105, filed March 14, 2008, entitled "Systems for Highly Efficient Solar Power", hereby incorporated by reference herein in its entirety.

Of course, the foregoing examples of how voltage output limits (8) may be relationally set and dynamically adjusted are intended to be illustrative and should not be construed as limiting the scope of how voltage output limits (8) may be relationally set and dynamically adjusted consistent with the principles discussed herein.

Dynamically adjusting voltage output limits (8) in some situations may cause photovoltaic DC-DC power converters (2) or solar energy sources (1) to operate in a suboptimal manner. For example, Fig. 5 and Fig. 6 illustrate that power converters typically exhibit varying degrees of power loss as the input voltage moves off of a peak value. As shown in the figures, power losses may increase the further the input voltage varies from the optimum. Since dynamically adjusting voltage output limits (8) may permit a power converter to operate across a wider range of input voltages, as shown for example in Fig. 6b, situations may arise where the converter becomes operated at a

suboptimal efficiency, a suboptimal input voltage, a suboptimal power loss, a suboptimal MPP voltage for a solar energy source (1), or the like. While it may seem counterintuitive, especially in light of conventional wisdom regarding solar power generation, the inventive technology described herein may permit and even encourage such suboptimal power converter operation to degrees not before contemplated. In particular, the suboptimal operation of individual power converters may permit greater gains in a solar power system (3) as a whole, for example such as by allowing more solar energy sources (1) to be operated at MPP, or perhaps to allow strings (27) to keep operating even despite substantial numbers of reduced panel functionalities or panel dropouts. Accordingly, a photovoltaic DC-DC power converter (2) in various embodiments may include controls to intentionally operate the converter in a suboptimal modality, such as a suboptimal efficiency control (14), a suboptimal input voltage control (15), a suboptimal power loss control (16), a suboptimal MPP voltage control (17), or the like.

In various embodiments, providing an external state parameter to a photovoltaic DC-DC power converter (2) may involve providing at least one intra-string parameter, such as wherein the external state parameter may be for a condition of some or all of a string (27) on which the converter is located. Similarly, embodiments may involve providing at least one inter-string parameter, such as wherein the external state parameter may be for a condition on some or all of a string (27) on which the power converter is not located. In this manner, a photovoltaic DC-DC power converter (2) in various embodiments perhaps may be responsive to an intra-string data interface (25) (responsive for example to conditions within a string (27) on which the converter is located) or an inter-string data interface (26) (responsive for example to conditions for a string (27) on which the converter is not located).

Intra-string and inter-string parameters may be utilized to achieve a desired condition for a string (27) or a desired inter-string condition when dynamically adjusting a voltage output limit (8). In this manner, a dynamically adjustable voltage output limit control (12) in fact may serve as an intra-string control or an inter-string control. Examples of desired intra-string conditions or inter-string conditions may include a desired voltage for the string or a desired inter-string voltage among strings (effected for

example perhaps by a desired string or inter-string voltage control), a nontraditionally high voltage for the string or a nontraditionally high inter-string voltage among strings (effected for example perhaps by a nontraditionally high string or inter-string voltage control), a near regulatory limit voltage for the string or near regulatory inter-string voltage among strings (effected for example perhaps by a near regulatory limit string or inter-string voltage control), or the like. Nontraditionally high voltages may be valued with respect to conventional solar power systems, which for example may typically be operated in the range of 200 volts to 400 volts. Similarly, near regulatory limit voltages may be valued with respect to a conventional regulatory limit voltage or regulatory voltage requirement, which for example frequently may be 600 volts.

Moreover, in certain embodiments, an intra-string or inter-string parameter may be greater than 400 volts for a string or an inter-string voltage of greater than 400 volts (effected for example perhaps by a 400 volt minimum string or inter-string voltage control), greater than 450 volts for a string or an inter-string voltage of greater than 450 volts (effected for example perhaps by a 450 volt minimum string or inter-string voltage control), greater than 500 volts for a string or an inter-string voltage of greater than 500 volts (effected for example perhaps by a 500 volt minimum string or inter-string voltage control), greater than 550 volts for a string or an inter-string voltage of greater than 550 volts (effected for example perhaps by a 550 volt minimum string or inter-string voltage control), greater than 65% of the regulatory voltage requirement for an intra-string voltage or inter-string voltage (effected for example perhaps by a 65% regulatory requirement minimum string or inter-string voltage control), greater than 70% of the regulatory voltage requirement for an intra-string voltage or inter-string voltage (effected for example perhaps by a 70% regulatory requirement minimum string or inter-string voltage control), greater than 75% of the regulatory voltage requirement for an intra-string voltage or inter-string voltage (effected for example perhaps by a 75% regulatory requirement minimum string or inter-string voltage control), greater than 80% of the regulatory voltage requirement for an intra-string voltage or inter-string voltage (effected for example perhaps by a 80% regulatory requirement minimum string or inter-string voltage control), greater than 85% of the regulatory voltage requirement for an intra-string voltage or inter-string voltage (effected for example perhaps by a 85% regulatory

requirement minimum string or inter-string voltage control), greater than 90% of the regulatory voltage requirement for an intra-string voltage or inter-string voltage (effected for example perhaps by a 90% regulatory requirement minimum string or inter-string voltage control), and greater than 95% of the regulatory voltage requirement for an intra-string voltage or inter-string voltage (effected for example perhaps by a 95% regulatory requirement minimum string or inter-string voltage control).

With further respect to the foregoing voltages, providing an intra-string parameter to a photovoltaic DC-DC power converter (2) in some embodiments may involve providing a voltage for the intra-string element. An intra-string element may be merely something else located on the same string (27) on which the converter may be located, such as perhaps the combination of another intra-string solar energy source (1) connected to another intra-string photovoltaic DC-DC power converter (2) serially located on the same string (27). In these cases, an intra-string data interface to which a photovoltaic DC-DC power converter (2) in various embodiments may be responsive may be an intra-string element voltage data interface.

Similarly, providing an inter-string parameter to a photovoltaic DC-DC power converter (2) in some embodiments may involve providing a voltage for an external string (27), such as perhaps a string (27) other than the string (27) on which the power converter is located. In these cases, an inter-string data interface to which a photovoltaic DC-DC power converter (2) in various embodiments may be responsive may be an external string voltage data interface.

Moreover, dynamically adjusting a voltage output limit (8) for the power converter may involve utilizing the intra-string or inter-string parameter to achieve a desired condition for a string (27), desired inter-string condition, or the like. For example, such utilization may involve compensating for the voltage of an intra-string element or external string (27) (for example, such as wherein an intra-string control may be an intra-string element voltage compensation control and an inter-string control may be an external string voltage compensation control), perhaps such as consistent with the principles described elsewhere herein.

Various embodiments may involve compensating for an increased voltage output (for example, such as a voltage spike caused by reflectivity or other high insolation

conditions) of an intra-string element or external string (utilizing for example perhaps an intra-string solar energy source or external string voltage output increase compensation control), compensating for a decreased voltage output (for example, such as clouding or other low insolation conditions) of an intra-string element or external string (utilizing for example perhaps an intra-string solar energy source or external string voltage output decrease compensation control), compensating for dropout (for example, such as sudden failure of one or more sources on a string) of an intra-string element or external string (utilizing for example perhaps an intra-string solar energy source or external string voltage output dropout compensation control), compensating for shading (for example, such as due to daily or seasonal moving patterns of shade) of an intra-string element or external string (utilizing for example perhaps a shaded intra-string solar energy source or external string compensation control), compensating for blockage (for example, such as due to the buildup of dirt or other debris) of an intra-string element or external string (utilizing for example perhaps a blocked intra-string solar energy source or external string compensation control), compensating for damage (for example, such as due to weather, manmade, or other events) to an intra-string element or external string (utilizing for example perhaps a damaged intra-string or external string solar energy source compensation control), compensating for malfunctioning (for example, due to mechanical failures or other causes) of an intra-string element or external string (utilizing for example perhaps an intra-string solar energy source or external string malfunction compensation control), compensating for non-uniformity (for example, due to different makes or models of equipment) in an intra-string element or external string (utilizing for example perhaps a non-uniform intra-string solar energy source or external string compensation control), or the like.

Of course, the inventive technology should be considered to encompass plural embodiments of the methods and apparatus discussed herein. For example, embodiments may include a plurality of solar energy sources (1), each having a DC photovoltaic output, and a plurality of photovoltaic DC-DC power converters (2), each having a DC photovoltaic input that accepts power from at least one DC photovoltaic output, an external state data interface (7), a dynamically adjustable voltage output limit control (12), and a converted DC photovoltaic output. Dynamically adjusting a voltage output

limit (8) for a photovoltaic DC-DC power converter (2) of course may include dynamically adjusting voltage output limits (8) for a plurality of power converters in any combination consistent with the principles discussed herein, perhaps including power converters located on the same string (27) or even different strings (27), and perhaps
5 utilizing any combination of intra-string and inter-string parameters, data interfaces, and controls as may be appropriate to achieve any desired string conditions or even inter-string conditions. Similarly, providing an external state parameter to a photovoltaic DC-DC power converter (2) may include providing any number of external state parameters to any plurality of power converters in any combination, and dynamically adjustable
10 voltage output limits (8) may be relationally set or dynamically adjusted in relation to the provided external state parameters in any plurality of power converters in any combination, all as consistent with the principles discussed herein. As but one example, some situations may involve providing a voltage output of one photovoltaic DC-DC power converter (2) to another photovoltaic DC-DC power converter (2), and relationally
15 setting a voltage output limit (8) in response thereto, though of course this example is merely illustrative and should not be construed to limit the various possible combinations as just described.

As can be easily understood from the foregoing, the basic concepts of the present inventive technology may be embodied in a variety of ways. It involves both voltage
20 output limitation techniques as well as devices to accomplish the appropriate voltage output limiting. In this application, the voltage output limitation techniques are disclosed as part of the results shown to be achieved by the various devices described and as steps which are inherent to utilization. They are simply the natural result of utilizing the devices as intended and described. In addition, while some devices are disclosed, it
25 should be understood that these not only accomplish certain methods but also can be varied in a number of ways. Importantly, as to all of the foregoing, all of these facets should be understood to be encompassed by this disclosure.

The discussion included in this patent application is intended to serve as a basic description. The reader should be aware that the specific discussion may not explicitly
30 describe all embodiments possible; many alternatives are implicit. It also may not fully explain the generic nature of the inventive technology and may not explicitly show how

each feature or element can actually be representative of a broader function or of a great variety of alternative or equivalent elements. Again, these are implicitly included in this disclosure. Where the inventive technology is described in device-oriented terminology, each element of the device implicitly performs a function. Apparatus claims may not only be included for the device described, but also method or process claims may be included to address the functions the inventive technology and each element performs. Neither the description nor the terminology is intended to limit the scope of the claims that will be included in any subsequent patent application.

It should also be understood that a variety of changes may be made without departing from the essence of the inventive technology. Such changes are also implicitly included in the description. They still fall within the scope of this inventive technology. A broad disclosure encompassing both the explicit embodiment(s) shown, the great variety of implicit alternative embodiments, and the broad methods or processes and the like are encompassed by this disclosure and may be relied upon when drafting the claims for any subsequent patent application. It should be understood that such language changes and broader or more detailed claiming may be accomplished at a later date (such as by any required deadline) or in the event the applicant subsequently seeks a patent filing based on this filing. With this understanding, the reader should be aware that this disclosure is to be understood to support any subsequently filed patent application that may seek examination of as broad a base of claims as deemed within the applicant's right and may be designed to yield a patent covering numerous aspects of the inventive technology both independently and as an overall system.

Further, each of the various elements of the inventive technology and claims may also be achieved in a variety of manners. Additionally, when used or implied, an element is to be understood as encompassing individual as well as plural structures that may or may not be physically connected. This disclosure should be understood to encompass each such variation, be it a variation of an embodiment of any apparatus embodiment, a method or process embodiment, or even merely a variation of any element of these. Particularly, it should be understood that as the disclosure relates to elements of the inventive technology, the words for each element may be expressed by equivalent apparatus terms or method terms -- even if only the function or result is the same. Such

equivalent, broader, or even more generic terms should be considered to be encompassed in the description of each element or action. Such terms can be substituted where desired to make explicit the implicitly broad coverage to which this inventive technology is entitled. As but one example, it should be understood that all actions may be expressed
5 as a means for taking that action or as an element which causes that action. Similarly, each physical element disclosed should be understood to encompass a disclosure of the action which that physical element facilitates. Regarding this last aspect, as but one example, the disclosure of a “converter” should be understood to encompass disclosure of the act of “converting” -- whether explicitly discussed or not -- and, conversely, were
10 there effectively disclosure of the act of “converting”, such a disclosure should be understood to encompass disclosure of a “converter” and even a “means for converting.” Such changes and alternative terms are to be understood to be explicitly included in the description.

Any patents, publications, or other references mentioned in this application for
15 patent are hereby incorporated by reference. Any priority case(s) claimed by this application is hereby appended and hereby incorporated by reference. In addition, as to each term used it should be understood that unless its utilization in this application is inconsistent with a broadly supporting interpretation, common dictionary definitions should be understood as incorporated for each term and all definitions, alternative terms,
20 and synonyms such as contained in the Random House Webster’s Unabridged Dictionary, second edition are hereby incorporated by reference. Finally, all references listed in the list of References To Be Incorporated By Reference or other information statement filed with the application or in the table below are hereby appended and hereby incorporated by reference in their entirety, however, as to each of the above, to the extent
25 that such information or statements incorporated by reference might be considered inconsistent with the patenting of this/these inventive technology(s) such statements are expressly not to be considered as made by the applicant(s).

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Thus, the applicant(s) should be understood to have support to claim and make a statement of invention to at least: i) each of the solar power devices as herein disclosed and described, ii) the related methods disclosed and described, iii) similar, equivalent, and even implicit variations of each of these devices and methods, iv) those alternative designs which accomplish each of the functions shown as are disclosed and described, v) those alternative designs and methods which accomplish each of the functions shown as are implicit to accomplish that which is disclosed and described, vi) each feature, component, and step shown as separate and independent inventions, vii) the applications enhanced by the various systems or components disclosed, viii) the resulting products produced by such systems or components, ix) each system, method, and element shown or described as now applied to any specific field or devices mentioned, x) methods and apparatuses substantially as described hereinbefore and with reference to any of the accompanying examples, xi) the various combinations and permutations of each of the

elements disclosed, xii) each potentially dependent claim or concept as a dependency on each and every one of the independent claims or concepts presented, and xiii) all inventions described herein.

With regard to claims whether now or later presented for examination, it should
5 be understood that for practical reasons and so as to avoid great expansion of the examination burden, the applicant may at any time present only initial claims or perhaps only initial claims with only initial dependencies. The office and any third persons interested in potential scope of this or subsequent applications should understand that broader claims may be presented at a later date in this case, in a case claiming the benefit
10 of this case, or in any continuation in spite of any preliminary amendments, other amendments, claim language, or arguments presented, thus throughout the pendency of any case there is no intention to disclaim or surrender any potential subject matter. It should be understood that if or when broader claims are presented, such may require that any relevant prior art that may have been considered at any prior time may need to be re-
15 visited since it is possible that to the extent any amendments, claim language, or arguments presented in this or any subsequent application are considered as made to avoid such prior art, such reasons may be eliminated by later presented claims or the like. Both the examiner and any person otherwise interested in existing or later potential coverage, or considering if there has at any time been any possibility of an indication of
20 disclaimer or surrender of potential coverage, should be aware that no such surrender or disclaimer is ever intended or ever exists in this or any subsequent application. Limitations such as arose in *Hakim v. Cannon Avent Group, PLC*, 479 F.3d 1313 (Fed. Cir 2007), or the like are expressly not intended in this or any subsequent related matter. In addition, support should be understood to exist to the degree required under new
25 matter laws -- including but not limited to European Patent Convention Article 123(2) and United States Patent Law 35 USC 132 or other such laws-- to permit the addition of any of the various dependencies or other elements presented under one independent claim or concept as dependencies or elements under any other independent claim or concept. In drafting any claims at any time whether in this application or in any subsequent
30 application, it should also be understood that the applicant has intended to capture as full and broad a scope of coverage as legally available. To the extent that insubstantial

substitutes are made, to the extent that the applicant did not in fact draft any claim so as to literally encompass any particular embodiment, and to the extent otherwise applicable, the applicant should not be understood to have in any way intended to or actually relinquished such coverage as the applicant simply may not have been able to anticipate
5 all eventualities; one skilled in the art, should not be reasonably expected to have drafted a claim that would have literally encompassed such alternative embodiments.

Further, if or when used, the use of the transitional phrase “comprising” is used to maintain the “open-end” claims herein, according to traditional claim interpretation. Thus, unless the context requires otherwise, it should be understood that the term
10 “comprise” or variations such as “comprises” or “comprising”, are intended to imply the inclusion of a stated element or step or group of elements or steps but not the exclusion of any other element or step or group of elements or steps. Such terms should be interpreted in their most expansive form so as to afford the applicant the broadest coverage legally permissible. The use of the phrase, “or any other claim” is used to provide support for
15 any claim to be dependent on any other claim, such as another dependent claim, another independent claim, a previously listed claim, a subsequently listed claim, and the like. As one clarifying example, if a claim were dependent “on claim 20 or any other claim” or the like, it could be re-drafted as dependent on claim 1, claim 15, or even claim 715 (if such were to exist) if desired and still fall with the disclosure. It should be understood
20 that this phrase also provides support for any combination of elements in the claims and even incorporates any desired proper antecedent basis for certain claim combinations such as with combinations of method, apparatus, process, and the like claims.

Finally, any claims set forth at any time are hereby incorporated by reference as part of this description of the inventive technology, and the applicant expressly reserves
25 the right to use all of or a portion of such incorporated content of such claims as additional description to support any of or all of the claims or any element or component thereof, and the applicant further expressly reserves the right to move any portion of or all of the incorporated content of such claims or any element or component thereof from the description into the claims or vice-versa as necessary to define the matter for which
30 protection is sought by this application or by any subsequent continuation, division, or continuation-in-part application thereof, or to obtain any benefit of, reduction in fees

pursuant to, or to comply with the patent laws, rules, or regulations of any country or treaty, and such content incorporated by reference shall survive during the entire pendency of this application including any subsequent continuation, division, or continuation-in-part application thereof or any reissue or extension thereon.

CLAIMS

What is claimed is:

- 5 1. A method of solar energy power conversion comprising the steps of:
- creating an MPP voltage DC photovoltaic output from at least one solar panel;
 - establishing said MPP voltage DC photovoltaic output as an MPP voltage DC photovoltaic input to a photovoltaic DC-DC power converter;
 - 10 • providing at least one external power converter voltage parameter to said photovoltaic DC-DC power converter;
 - dynamically adjusting a voltage output limit of said photovoltaic DC-DC power converter in relation to said provided external power converter voltage parameter;
 - 15 • compensating for an external power converter voltage via said step of dynamically adjusting a voltage output limit of said photovoltaic DC-DC power converter;
 - slaving said step of dynamically adjusting a voltage output limit of said photovoltaic DC-DC power converter to a regulatory voltage limit;
 - 20 • converting said MPP voltage DC photovoltaic input with said photovoltaic DC-DC power converter utilizing said dynamically adjusted voltage output limit into a converted DC photovoltaic output;
 - establishing said converted DC photovoltaic output as a converted DC photovoltaic input to a DC-AC inverter;
 - 25 • inverting said converted DC photovoltaic input into an inverted AC photovoltaic output.
2. A method of solar energy power conversion as described in claim 1 wherein said step of compensating comprises the step of raising a voltage output limit of said photovoltaic DC-DC power converter in response to a voltage drop of said external power converter voltage parameter.
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3. A method of solar energy power conversion as described in claim 1 wherein said step of compensating comprises the step of lowering a voltage output limit of said photovoltaic DC-DC power converter in response to a voltage gain of said external power converter voltage parameter.
4. A method of solar energy power conversion as described in claim 1 wherein said step of providing at least one external power converter voltage parameter comprises the step of providing at least one intra-string parameter, and wherein said step of dynamically adjusting a voltage output limit comprises the step of utilizing said at least one intra-string parameter to achieve a desired condition for a string.
5. A method of solar energy power conversion as described in claim 4 wherein said desired condition for a string comprises a condition selected from the group consisting of a desired voltage for said string, a nontraditionally high voltage for said string, a near regulatory limit voltage for said string, greater than 400 volts for said string, greater than 450 volts for said string, greater than 500 volts for said string, greater than 550 volts for said string, greater than 65% of a regulatory voltage requirement for said string, greater than 70% of a regulatory voltage requirement for said string, greater than 75% of a regulatory voltage requirement for said string, greater than 80% of a regulatory voltage requirement for said string, greater than 85% of a regulatory voltage requirement for said string, greater than 90% of a regulatory voltage requirement for said string, and greater than 95% of a regulatory voltage requirement for said string.
6. A method of solar energy power conversion as described in claim 4 wherein said step of compensating comprises the step of compensating selected from the group consisting of compensating for an increased voltage output of at least one intra-string solar panel, compensating for a decreased voltage output

of at least one intra-string solar panel, compensating for dropout of at least one intra-string solar panel, compensating for shading of at least one intra-string solar panel, compensating for blockage of at least one intra-string solar panel, compensating for damage to at least one intra-string solar panel, compensating for malfunctioning of at least one intra-string solar panel, and compensating for non-uniformity in at least one intra-string solar panel.

7. A solar energy power conversion apparatus comprising:

- at least one solar panel having a DC photovoltaic output;
- maximum photovoltaic power point converter functionality control circuitry to which said at least one solar panel is responsive;
- a photovoltaic DC-DC power converter having a DC photovoltaic input that accepts power from said DC photovoltaic output;
- at least one external power converter voltage output data interface of said photovoltaic DC-DC power converter;
- a dynamically adjustable voltage output limit compensation control of said photovoltaic DC-DC power converter relationally responsive to said at least one external power converter voltage output data interface;
- a regulatory slaved primary control to which said dynamically adjustable voltage output limit compensation control of said photovoltaic DC-DC power converter is relationally responsive;
- at least one converted DC photovoltaic output of said photovoltaic DC-DC power converter;
- a photovoltaic DC-AC inverter input responsive to said converted DC photovoltaic output of said photovoltaic DC-DC power converter;
- a photovoltaic AC power output responsive to said photovoltaic DC-AC inverter.

8. A solar energy power conversion apparatus as described in claim 7 wherein said dynamically adjustable voltage output limit compensation control

comprises an external power converter voltage output drop detector and a voltage output limit increase control.

9. A solar energy power conversion apparatus as described in claim 7 wherein
5 said dynamically adjustable voltage output limit compensation control comprises an external power converter voltage output gain detector and a voltage output limit decrease control.
10. A solar energy power conversion apparatus as described in claim 7 wherein
10 said at least one external power converter voltage output data interface comprises at least one intra-string data interface and wherein said dynamically adjustable voltage output limit compensation control comprises an intra-string control.
- 15 11. A solar energy power conversion apparatus as described in claim 10 wherein said intra-string control comprises a control selected from the group consisting of a desired string voltage control, a nontraditionally high string voltage control, a near regulatory limit string voltage control, a 400 volt minimum
20 string voltage control, a 450 volt minimum string voltage control, a 500 volt minimum string voltage control, a 550 volt minimum string voltage control, a 65% regulatory requirement minimum string voltage control, a 70% regulatory requirement minimum string voltage control, a 75% regulatory requirement minimum string voltage control, a 80% regulatory requirement minimum string voltage control, a 85% regulatory requirement minimum
25 string voltage control, a 90% regulatory requirement minimum string voltage control, and a 95% regulatory requirement minimum string voltage control.
12. A solar energy power conversion apparatus as described in claim 10 wherein
30 said dynamically adjustable voltage output limit compensation control comprises a control selected from the group consisting of an intra-string solar panel voltage output increase compensation control, an intra-string solar panel

voltage output decrease compensation control, an intra-string solar panel dropout compensation control, a shaded intra-string solar panel compensation control, a blocked intra-string solar panel compensation control, a damaged intra-string solar panel compensation control, an intra-string solar panel malfunction compensation control, and a non-uniform intra-string solar panel compensation control.

13. A method of solar energy power conversion comprising the steps of:
- creating a DC photovoltaic output from at least one solar energy source;
 - establishing said DC photovoltaic output as a DC photovoltaic input to a photovoltaic DC-DC power converter;
 - providing at least one external state parameter to said photovoltaic DC-DC power converter;
 - relationally setting a dynamically adjustable voltage output limit of said photovoltaic DC-DC power converter in relation to said at least one external state parameter;
 - converting said DC photovoltaic input with said photovoltaic DC-DC power converter utilizing said dynamically adjustable voltage output limit into a converted DC photovoltaic output.
14. A method of solar energy power conversion as described in claim 13 wherein said solar energy source comprises a solar energy source selected from the group consisting of at least one solar cell, a plurality of electrically connected solar cells, a plurality of adjacent electrically connected solar cells, at least one solar panel, a plurality of electrically connected solar panels, and at least one string of electrically connected solar panels.
15. A method of solar energy power conversion as described in claim 13 wherein said step of creating a DC photovoltaic output from said at least one solar energy source comprises the step of creating MPP voltage for said at least one solar energy source.

16. A method of solar energy power conversion as described in claim 13 wherein said step of providing at least one external state parameter to said photovoltaic DC-DC power converter comprises the step of providing at least one external state parameter selected from the group consisting of a voltage parameter, a current parameter, a power parameter, an insolation parameter, a temperature parameter, a system status parameter, a demand status parameter, a power converter output parameter, a string output parameter, a historical data tracking parameter, and a regulatory requirement parameter.
17. A method of solar energy power conversion as described in claim 13 wherein said step of providing at least one external state parameter to said photovoltaic DC-DC power converter comprises the step of providing at least one multi-parametric external state parameter.
18. A method of solar energy power conversion as described in claim 17 wherein said step of providing at least one multi-parametric external state parameter comprises the step of including a parametric component for said at least one multi-parametric external state parameter selected from the group consisting of a voltage parameter, a current parameter, a power parameter, an insolation parameter, a temperature parameter, a system status parameter, a demand status parameter, a power converter output parameter, a string output parameter, a historical data tracking parameter, and a regulatory requirement parameter.
19. A method of solar energy power conversion as described in claim 13 wherein said step of relationally setting a dynamically adjustable voltage output limit comprises the step of dynamically adjusting said dynamically adjustable voltage output limit responsive to said at least one external state parameter.

20. A method of solar energy power conversion as described in claim 19 wherein said step of dynamically adjusting said dynamically adjustable voltage output limit comprises a step selected from the group consisting of operating said photovoltaic DC-DC power converter at a suboptimal efficiency, operating
5 said photovoltaic DC-DC power converter at a suboptimal input voltage, operating said photovoltaic DC-DC power converter at a suboptimal power loss, and operating said at least one solar energy source at a suboptimal MPP voltage.
- 10 21. A method of solar energy power conversion as described in claim 19 wherein said step of dynamically adjusting said dynamically adjustable voltage output limit comprises the steps of:
- implementing a step function to dynamically adjust said dynamically adjustable voltage output limit;
 - 15 • determining a resultant effect on said external state parameter;
 - repeating said steps of implementing and determining until a desired result is achieved.
- 20 22. A method of solar energy power conversion as described in claim 19 wherein said step of dynamically adjusting said dynamically adjustable voltage output limit comprises the step of first adjusting an external voltage to a safe condition.
- 25 23. A method of solar energy power conversion as described in claim 19 wherein said step of dynamically adjusting said dynamically adjustable voltage output limit comprises the step of compensating for said external state parameter.
- 30 24. A method of solar energy power conversion as described in claim 23 wherein said step of compensating for said external state parameter comprises the step of raising a voltage limit of said photovoltaic DC-DC power converter in response to a voltage drop of said external state parameter.

25. A method of solar energy power conversion as described in claim 23 wherein said step of compensating for said external state parameter comprises the step of lowering a voltage limit of said photovoltaic DC-DC power converter in response to a voltage gain of said external state parameter.
26. A method of solar energy power conversion as described in claim 13 wherein said step of relationally setting a dynamically adjustable voltage output limit comprises the step of slaving said dynamically adjustable voltage output limit of said photovoltaic DC-DC power converter in relation to said at least one external state parameter.
27. A method of solar energy power conversion as described in claim 26 wherein said step of slaving said dynamically adjustable voltage output limit comprises the step of hierarchically slaving said dynamically adjustable voltage output limit of said photovoltaic DC-DC power converter in relation to said at least one external state parameter.
28. A method of solar energy power conversion as described in claim 27 wherein said step of hierarchically slaving said dynamically adjustable voltage output limit comprises the steps of:
- first slaving to a regulatory parameter;
 - second slaving to an operational parameter;
 - third slaving to an MPP parameter.
29. A method of solar energy power conversion as described in claim 13 wherein said step of providing at least one external state parameter comprises the step of providing at least one intra-string parameter, and wherein said step of relationally setting a dynamically adjustable voltage output limit comprises the step of dynamically adjusting said dynamically adjustable voltage output

limit utilizing said at least one intra-string parameter to achieve a desired condition for a string.

30. A method of solar energy power conversion as described in claim 29 wherein
5 said desired condition for a string comprises a condition selected from the group consisting of a desired voltage for said string, a nontraditionally high voltage for said string, a near regulatory limit voltage for said string, greater than 400 volts for said string, greater than 450 volts for said string, greater than 500 volts for said string, greater than 550 volts for said string, greater
10 than 65% of a regulatory voltage requirement for said string, greater than 70% of a regulatory voltage requirement for said string, greater than 75% of a regulatory voltage requirement for said string, greater than 80% of a regulatory voltage requirement for said string, greater than 85% of a regulatory voltage requirement for said string, greater than 90% of a
15 regulatory voltage requirement for said string, and greater than 95% of a regulatory voltage requirement for said string.
31. A method of solar energy power conversion as described in claim 29 wherein
20 said step of providing at least one intra-string parameter comprises the step of providing a voltage for at least one intra-string element, and wherein said step of dynamically adjusting said dynamically adjustable voltage output limit comprises the step of compensating for said voltage for said at least one intra-string element.
- 25 32. A method of solar energy power conversion as described in claim 31 wherein said at least one intra-string element comprises at least one intra-string solar energy source connected to at least one intra-string photovoltaic DC-DC power converter serially located on said string.
- 30 33. A method of solar energy power conversion as described in claim 31 wherein said step of compensating for said voltage comprises the step of compensating

selected from the group consisting of compensating for an increased voltage output of at least one intra-string solar energy source, compensating for a decreased voltage output of at least one intra-string solar energy source, compensating for dropout of at least one intra-string solar energy source, compensating for shading of at least one intra-string solar energy source, compensating for blockage of at least one intra-string solar energy source, compensating for damage to at least one intra-string solar energy source, compensating for malfunctioning of at least one intra-string solar energy source, and compensating for non-uniformity in at least one intra-string solar energy source.

34. A method of solar energy power conversion as described in claim 29 further comprising the step of dynamically adjusting a dynamically adjustable voltage output limit for a plurality of photovoltaic DC-DC power converters utilizing said at least one intra-string parameter to achieve a desired condition for said string.

35. A method of solar energy power conversion as described in claim 13 wherein said step of providing at least one external state parameter comprises the step of providing at least one inter-string parameter, and wherein said step of relationally setting a dynamically adjustable voltage output limit comprises the step of dynamically adjusting said dynamically adjustable voltage output limit utilizing said at least one inter-string parameter to achieve a desired inter-string condition.

36. A method of solar energy power conversion as described in claim 35 wherein said desired inter-string condition comprises a condition selected from the group consisting of a desired inter-string voltage, a nontraditionally high inter-string voltage, an inter-string voltage close to a regulatory limit, an inter-string voltage of greater than 400 volts, an inter-string voltage of greater than 450 volts, an inter-string voltage of greater than 500 volts, an inter-string voltage

of greater than 550 volts, an inter-string voltage of greater than 65% of a regulatory voltage requirement, an inter-string voltage of greater than 70% of a regulatory voltage requirement, an inter-string voltage of greater than 75% of a regulatory voltage requirement, an inter-string voltage of greater than 80% of a regulatory voltage requirement, an inter-string voltage of greater than 85% of a regulatory voltage requirement, an inter-string voltage of greater than 90% of a regulatory voltage requirement, and an inter-string voltage of greater than 95% of a regulatory voltage requirement.

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- 10 37. A method of solar energy power conversion as described in claim 35 wherein said step of providing at least one inter-string parameter comprises the step of providing a voltage for at least one external string, and wherein said step of dynamically adjusting said dynamically adjustable voltage output limit comprises the step of compensating for said voltage for said at least one
- 15 external string.
38. A method of solar energy power conversion as described in claim 37 wherein said at least one external string comprises at least one parallel external string.
- 20 39. A method of solar energy power conversion as described in claim 37 wherein said step of compensating for said voltage comprises the step of compensating selected from the group consisting of compensating for an increased voltage output of at least one external string, compensating for a decreased voltage output of at least one external string, compensating for dropout of at least one
- 25 external string, compensating for shading of at least one external string, compensating for blockage of at least one external string, compensating for damage to at least one external string, compensating for malfunctioning of at least one external string, and compensating for non-uniformity in at least one external string.

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40. A method of solar energy power conversion as described in claim 35 further comprising a step selected from the group consisting of dynamically adjusting a dynamically adjustable voltage output limit for a plurality of photovoltaic DC-DC power converters utilizing said at least one inter-string parameter to achieve a desired inter-string condition, dynamically adjusting a dynamically adjustable voltage output limit for a plurality of photovoltaic DC-DC power converters on a single string utilizing said at least one inter-string parameter to achieve a desired inter-string condition, and dynamically adjusting a dynamically adjustable voltage output limit for a plurality of photovoltaic DC-DC power converters on a plurality of strings utilizing said at least one inter-string parameter to achieve a desired inter-string condition.
41. A method of solar energy power conversion as described in claim 13 further comprising the steps of:
- providing at least one external state parameter to a plurality of photovoltaic DC-DC power converters;
 - relationally setting a dynamically adjustable voltage output limit in multiple of said plurality of photovoltaic DC-DC power converters, each in relation to said provided at least one external state parameter.
42. A method of solar energy power conversion as described in claim 41 wherein said step of providing at least one external state parameter to a plurality of photovoltaic DC-DC power converters comprises the step of providing a state parameter of at least one photovoltaic DC-DC power converter to at least another photovoltaic DC-DC power converter, and wherein said step of relationally setting a dynamically adjustable voltage output limit comprises the step of relationally setting a dynamically adjustable voltage output limit in relation to said provided state parameter.
43. A method of solar energy power conversion as described in claim 13 further comprising the steps of:

- establishing said converted DC photovoltaic output as a converted DC photovoltaic input to a DC-AC inverter;
- inverting said converted DC photovoltaic input into an inverted AC photovoltaic output.

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44. A solar energy power conversion apparatus comprising:

- at least one solar energy source having a DC photovoltaic output;
- a photovoltaic DC-DC power converter having a DC photovoltaic input that accepts power from said DC photovoltaic output;
- 10 • at least one external state data interface of said photovoltaic DC-DC power converter;
- a dynamically adjustable voltage output limit control of said photovoltaic DC-DC power converter relationally responsive to said at least one external state data interface;
- 15 • at least one converted DC photovoltaic output of said photovoltaic DC-DC power converter.

45. A solar energy power conversion apparatus as described in claim 44 wherein said solar energy source comprises a solar energy source selected from the group consisting of at least one solar cell, a plurality of electrically connected solar cells, a plurality of adjacent electrically connected solar cells, at least one solar panel, a plurality of electrically connected solar panels, and at least one string of electrically connected solar panels.

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25 46. A solar energy power conversion apparatus as described in claim 44 further comprising maximum photovoltaic power point converter functionality control circuitry to which said at least one solar energy source is responsive.

47. A solar energy power conversion apparatus as described in claim 44 wherein said at least one external state data interface comprises an data interface selected from the group consisting of a voltage data interface, a current data

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interface, a power data interface, an insolation data interface, a temperature data interface, a system status data interface, a demand data interface, a power converter output data interface, a string output data interface, a historical data tracking data interface, and a regulatory requirement data interface.

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48. A solar energy power conversion apparatus as described in claim 44 wherein said at least one external state data interface comprises a multi-parametric data interface.

10 49.

A solar energy power conversion apparatus as described in claim 48 wherein said multi-parametric data interface comprises an data interface component selected from the group consisting of a voltage data interface component, a current data interface component, a power data interface component, an insolation data interface component, a temperature data interface component, a system status data interface component, a demand data interface component, a power converter output data interface component, a string output data interface component, a historical data tracking data interface component, and a regulatory requirement data interface component.

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20 50.

A solar energy power conversion apparatus as described in claim 44 wherein said dynamically adjustable voltage output limit control comprises a control selected from the group consisting of a suboptimal efficiency control for said photovoltaic DC-DC power converter, a suboptimal input voltage control for said photovoltaic DC-DC power converter, a suboptimal power loss control for said photovoltaic DC-DC power converter, and a suboptimal MPP voltage control for said at least one solar energy source.

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51. A solar energy power conversion apparatus as described in claim 44 wherein said dynamically adjustable voltage output limit control comprises a step function control.

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52. A solar energy power conversion apparatus as described in claim 44 wherein said dynamically adjustable voltage output limit control comprises an external voltage safeguard control.
- 5 53. A solar energy power conversion apparatus as described in claim 44 wherein said dynamically adjustable voltage output limit control comprises an external state parameter compensation control.
54. A solar energy power conversion apparatus as described in claim 53 wherein
10 said external state parameter compensation control comprises an external state parameter voltage drop detector and a voltage output limit increase control.
55. A solar energy power conversion apparatus as described in claim 53 wherein
15 said external state parameter compensation control comprises an external state parameter voltage gain detector and a voltage output limit decrease control.
56. A solar energy power conversion apparatus as described in claim 44 wherein
20 said dynamically adjustable voltage output limit control comprises a slaved dynamically adjustable voltage output limit control.
57. A solar energy power conversion apparatus as described in claim 56 wherein
said slaved dynamically adjustable voltage output limit control comprises a
hierarchically slaved dynamically adjustable voltage output limit control.
- 25 58. A solar energy power conversion apparatus as described in claim 57 wherein
said hierarchically slaved dynamically adjustable voltage output limit control
comprises:
- a regulatory slaved primary control;
 - an operationally slaved secondary control;
 - 30 • a MPP slaved tertiary control.

59. A solar energy power conversion apparatus as described in claim 44 wherein said at least one external state data interface comprises at least one intra-string data interface and wherein said dynamically adjustable voltage output limit control comprises an intra-string control.

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60. A solar energy power conversion apparatus as described in claim 59 wherein said intra-string control comprises a control selected from the group consisting of a desired string voltage control, a nontraditionally high string voltage control, a near regulatory limit string voltage control, a 400 volt minimum string voltage control, a 450 volt minimum string voltage control, a 500 volt minimum string voltage control, a 550 volt minimum string voltage control, a 65% regulatory requirement minimum string voltage control, a 70% regulatory requirement minimum string voltage control, a 75% regulatory requirement minimum string voltage control, a 80% regulatory requirement minimum string voltage control, a 85% regulatory requirement minimum string voltage control, a 90% regulatory requirement minimum string voltage control, and a 95% regulatory requirement minimum string voltage control.

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61. A solar energy power conversion apparatus as described in claim 59 wherein said at least one intra-string data interface comprises at least one intra-string element voltage data interface, and wherein said intra-string condition control comprises an intra-string element voltage compensation control.

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62. A solar energy power conversion apparatus as described in claim 61 wherein said intra-string element voltage compensation control comprises a control selected from the group consisting of an intra-string solar energy source voltage output increase compensation control, an intra-string solar energy source voltage output decrease compensation control, an intra-string solar energy source dropout compensation control, a shaded intra-string solar energy source compensation control, a blocked intra-string solar energy source compensation control, a damaged intra-string solar energy source

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compensation control, an intra-string solar energy source malfunction compensation control, and a non-uniform intra-string solar energy source compensation control.

- 5 63. A solar energy power conversion apparatus as described in claim 59 further comprising a plurality of photovoltaic DC-DC power converters, each having an intra-string condition control responsive to at least one intra-string data interface.
- 10 64. A solar energy power conversion apparatus as described in claim 44 wherein said at least one external state data interface comprises at least one inter-string data interface and wherein said dynamically adjustable voltage output limit control comprises an inter-string control.
- 15 65. A solar energy power conversion apparatus as described in claim 64 wherein said inter-string condition control comprises a control selected from the group consisting of a desired inter-string voltage control, a nontraditionally high inter-string voltage control, a near regulatory limit inter-string voltage control, a 400 volt minimum inter-string voltage control, a 450 volt minimum inter-string voltage control, a 500 volt minimum inter-string voltage control, a 550
20 volt minimum inter-string voltage control, a 65% regulatory requirement minimum inter-string voltage control, a 70% regulatory requirement minimum inter-string voltage control, a 75% regulatory requirement minimum inter-string voltage control, a 80% regulatory requirement minimum inter-string
25 voltage control, a 85% regulatory requirement minimum inter-string voltage control, a 90% regulatory requirement minimum inter-string voltage control, and a 95% regulatory requirement minimum inter-string voltage control.
- 30 66. A solar energy power conversion apparatus as described in claim 64 wherein said at least one inter-string data interface comprises at least one external

string voltage data interface, and wherein said inter-string condition control comprises an external string voltage compensation control.

67. A solar energy power conversion apparatus as described in claim 66 wherein
5 said at least one external string comprises at least one parallel external string.

68. A solar energy power conversion apparatus as described in claim 66 wherein
said external string voltage compensation control comprises a control selected
10 from the group consisting of an external string voltage output increase
compensation control, an external string voltage output decrease
compensation control, an external string dropout compensation control, a
shaded external string compensation control, a blocked external string
compensation control, a damaged external string compensation control, an
external string malfunction compensation control, and a non-uniform external
15 string compensation control.

69. A solar energy power conversion apparatus as described in claim 64 further
comprising a plurality of photovoltaic DC-DC power converters, each having
at least one inter-string data interface and an inter-string condition control
20 responsive thereto.

70. A solar energy power conversion apparatus as described in claim 44 further
comprising:
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- a plurality of solar energy sources, each having a DC photovoltaic output;
- a plurality of photovoltaic DC-DC power converters, each having a DC
photovoltaic input that accepts power from one of said DC photovoltaic
outputs;
- at least one external state data interface of each said photovoltaic DC-DC
power converter;
- 30 • a dynamically adjustable voltage output limit control of each said
photovoltaic DC-DC power converter relationally responsive to each said

external state data interface of each said photovoltaic DC-DC power converter;

- at least one converted DC photovoltaic output of each said photovoltaic DC-DC power converter.

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71. A solar energy power conversion apparatus as described in claim 70 wherein at least one said external state data interface comprises an external state data interface of one said photovoltaic DC-DC power converter responsive to a voltage output of at least another said photovoltaic DC-DC power converter.

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72. A solar energy power conversion apparatus as described in claim 44 further comprising:

- a photovoltaic DC-AC inverter input responsive to said converted DC photovoltaic output of said photovoltaic DC-DC power converter;
- a photovoltaic AC power output responsive to said photovoltaic DC-AC inverter.

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73. A system substantially as herein described with reference to any one or more of the Figures and Description.

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74. The process according to any of claims 44 to 72 and further comprising any of the steps as shown in Figures 1-8, separately, in any combination or permutation.