VOLTAGE SUMMATION FOR MAXIMUM POWER GENERATION

PROVISIONAL APPLICATION

Background of the Invention

The invention relates to power generation fields, where there are several power sources which are connected in serial in order to generate higher voltage from several low voltage power sources.

A typical application is in conjunction with a Photo-Voltaic (PV) solar energy generation field, where several PV panels are connected serially. Another typical application is in conjunction with Concentrated Photo Voltaic (CPV) solar energy generation, where groups of cells are connected serially.

When power sources are connected serially, the electric current that flows through them is equal. When all the sources are matched, all the sources generate the same current and there is no power loss effect. However, typically, the sources are not exactly matched. Some are weaker and provide less current than others. This is caused by component performance variation, partial sun blocking or variation of the sun flux density in CPV systems.

In these situations, the weaker source determines the current that flows in the system. The overall power generated is smaller than the total available power since the weaker source cannot accommodate the current drive of the stronger sources.

The invention provides a solution which utilizes the available power of all the power sources without the limiting effect of weaker sources.

Related Art

An obvious solution for the described problem is to generate power from each source separately. It eliminates the dependency between the sources but is a relatively expensive solution. A separate inverter to translate the DC sources to an AC source that can be connected to the electrical grid has to be provided for each source. The following publications describe this technology:

- US20080150366 entitled "HIGH RELIABILITY POWER SYSTEMS AND SOLAR POWER CONVERTERS
- US20090039852 entitled "DIGITAL AVERAGE INPUT CURRENT CONTROL IN POWER CONVERTER"
- US20090140715 entitled "SAFETY MECHANISMS, WAKE UP AND SHUTDOWN METHODS IN DISTRIBUTED POWER INSTALLATIONS"
- US20090147554 entitled "PARALLEL CONNECTED INVERTERS"

- Cascaded DC-DC Converter Connection of Photovoltaic Modules; G. R. Walker, P. C. Sernia; School of Information Technology and Electrical Engineering, University of Queensland

Another obvious configuration is to collect the power available from each source by connecting the sources in a parallel configuration rather than in a serial configuration. The drawback of this configuration is that in a parallel configuration each source must provide an equal voltage. Once again, the weaker source, providing the lowest voltage, will determine the total voltage available. Another issue with such a solution is that the available total voltage of this configuration is significantly lower. It makes the conversion to the higher AC line voltage more complicated and less effective due to the voltage boost stage it has to include.

Recently, new configurations have been introduced into the market, which solve the described problem. In these configurations a separate DC to DC converter is connected to each power source. These converters track the available power of each source and provide a matching impedance to the source, thereby extracting the maximum available power. At its respective output each converter provides the same current with different voltages as dictated by the power extracted from the source. Since the currents available from all the converters are equal, they can be connected serially while providing the voltage required by the AC converter. This configuration is presented in Figure 1:

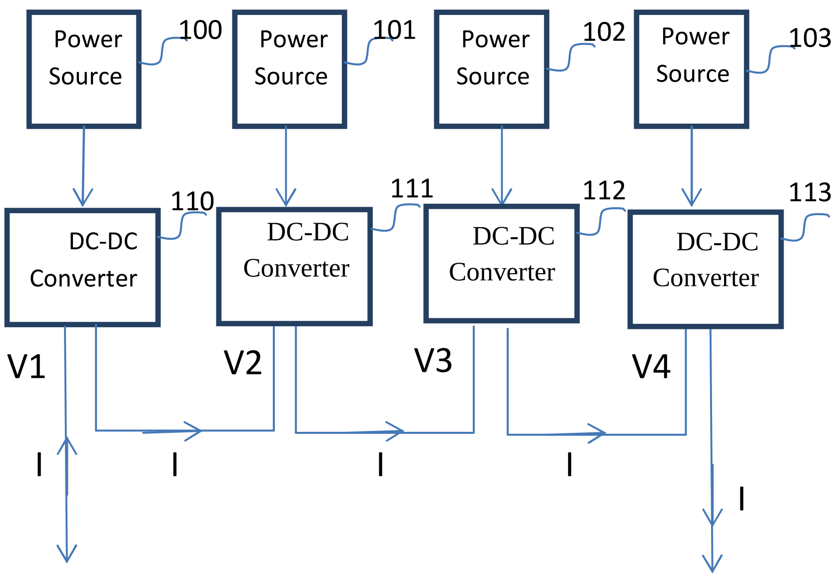

Figure 1: Prior art optimal power summation

Power sources 100 – 103 generate different voltages and currents. Each source is connected to a separate DC-DC converter (110-113 respectively) which extracts the source's maximum available power. At their respective outputs, each of the DC-DC converters generates the same current "I" with different voltages V1 –V4 respectively. The voltages are summed to generate the system output voltage of V1+V2+V3+V4 with current I.

Assuming lossless DC-DC converters, converter 110 output power which is V1*I is equal to the maximum available power of power source 100. Similarly V2*I, V3*I and V4*I equal the maximum available power of power sources 101, 102 and 103 respectively.

The total output power of the system is (V1+V2+V3+V4)*I= V1*I + V2*I + V3*I + V4*I, which is equal to the total available power of the sources.

The following publications describe this technology:

- US20080150366 entitled "METHOD FOR DISTRIBUTED POWER HARVESTING USING DC POWER SOURCES"
- US20090039852 entitled "DIGITAL AVERAGE INPUT CURRENT CONTROL IN POWER CONVERTER"
- US20090140715 entitled "SAFETY MECHANISMS, WAKE UP AND SHUTDOWN METHODS IN DISTRIBUTED POWER INSTALLATIONS"
- US20090147554 entitled "PARALLEL CONNECTED INVERTERS"
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Another solution is presented in:

"PV STRING PER-MODULE MAXIMUM POWER POINT ENABLING CONVERTERS"; G.R. Walker, J. Xue and P. Sernia, School of Information Technology and Electrical Engineering, The University of Queensland.

This article describes a scheme of connecting DC-DC converters in parallel to the power sources diverting the extra current available from each individual source around the weaker sources.

Summary of the Invention

A drawback of the related art presented in Figure 1 is that each of the DC-DC converters has to convert the full power available from each of the power sources. This requires these converters to be large and expensive. Additionally, the efficiency of these DC-DC converters affects the overall power generated by the system.

The present invention overcomes these drawbacks by using the following arrangement:

The power sources are connected serially in a conventional configuration, and the current flowing through all of the power sources is equal to the current available from the weakest source. Additionally, DC-DC converters are connected to the stronger sources which are capable of delivering more current than the current flowing through the serial connection. These DC-DC converters draw the extra available current from each of the stronger sources enabling them to provide their maximum available power. It is a particular feature of the present invention that these DC-DC converters may be relatively small and inexpensive since they merely need to convert the extra available current from each of the stronger sources, vs. the converters used in the prior art which need to convert the entire current provided from each source.

The DC-DC converters convert the extra available current of the stronger power sources to a lower voltage current which is equal to the current flowing through the serial connection. Since the output current of the DC-DC converters is equal to the serial connection current, their outputs can be connected serially to generate the full output power. Figure 2 presents the proposed configuration.

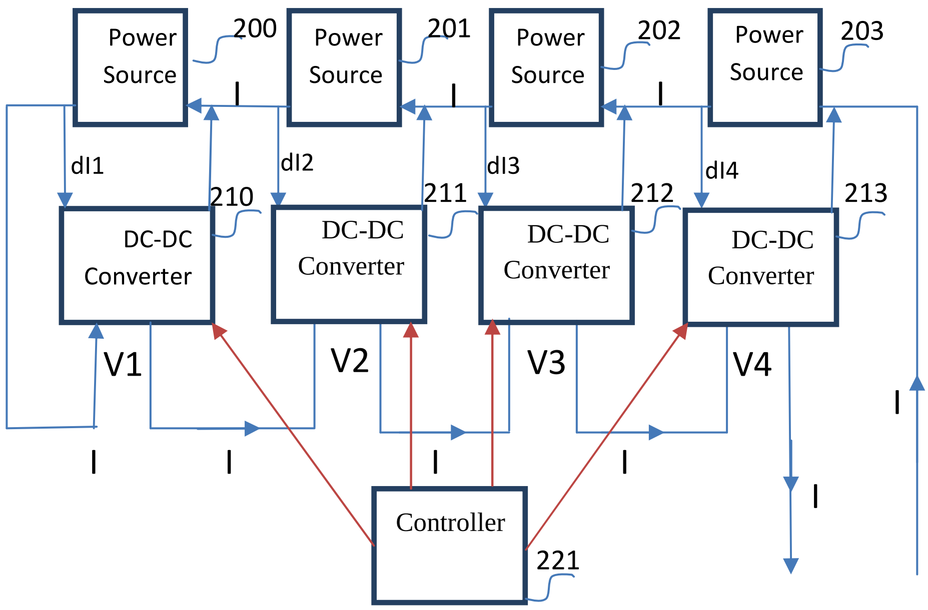

Figure 2: Proposed Configuration

Power sources 200-203 are connected serially with current "I" flowing through them. DC-DC converters 210-213 are connected in parallel to the outputs of power sources 200-203, drawing extra available currents dI1-dI4. This extra available current is drawn from the power sources at the full voltage levels of the power source output (parallel connection at the output). The DC-DC converters transform the full voltage/low current inputs to low voltage/full current ("I") outputs. These outputs V1-V4 are connected in serial form to the output of the power sources, thereby raising the voltage to generate the maximum available power.

Controller 221 controls the amount of current drawn by the DC/DC converters. Typically the controller controls a Pulse Width Modulation (PWM) mechanism within each of the DC/DC converters. The controller executes an algorithm which maximizes the amount of power generated by the system. An example of such an algorithm is presented below:

1. Ramp through the current drawn by DC\DC converter 210.
2. Monitor the total power generated by the system.
3. Set the current drawn by DC\DC converter 210 to the one that generates the maximum total power in step 1. Monitor the change in current drawn by the DC\DC converter 210 relative to the previous setting of the DC\DC converter.
4. Repeat steps 1 to 3 for the rest of the DC\DC converters.
5. Repeat steps 1 to 4 until the correction in the of all DC/DC converters is below a preset threshold.

Steps 1 to 3 of the presented algorithm determine a local maximum of the generated total power based on configuring one of the DC\DC converters. Since there is a dependency between the power drawn by one converter and the setting of the other converters, the algorithm cycles repeatedly through the converters until convergence to the optimal settings is reached.

The following example demonstrates the operation of the present invention:

Assume the following power sources are available:

1. 50V - 24A
2. 51V - 25A
3. 51V - 26A
4. 52V - 27A

Connecting the sources serially will provide the following performance:

Vout = 204V

Iout = 24A (the weaker power source determines the output current)

Pout = 4896 W

Using the configuration presented in figure 1, we assume that the DC-DC converters are arranged to generate 30A outputs. We assume as well that DC-DC converters efficiency is 95%.

The outputs of the DC-DC converters will be:

1. Voltage=50*24*.95/30 = 38V; Current = 30A; Power = 1140 W
2. Voltage=51*25*.95/30 = 40.375V; Current = 30A; Power = 1211.25 W
3. Voltage=51*26*.95/30 = 41.99V; Current = 30A; Power = 1259.7 W
4. Voltage=52*27*.95/30 = 44.46V; Current = 30A; Power = 1333.8 W

The total output generated voltage will be:

38V + 40.375V + 41.99V + 44.46V = 164.825V

The total power will be:

1140W + 1211.25W + 1259.7W + 1333.8W = 4944.75W

We gain close to 50 W by using 4 DC-DC converters each with more than 1 KW output.

Using the proposed configuration of the present invention as shown in Fig. 2, we will establish the serial current at 24 A which is the current of source 1, while extracting the extra available currents from the stronger 3 power sources to DC-DC converters. Their output will be set to 24 A as well. Assuming again 95% efficiency the following voltages will be generated:

1. V1 = 0; This is the weakest source
2. V2 = 51*(25-24)*.95/24 = 2.02 V; Power = 48.45 W
3. V3 = 51*(26-24)*.95/24 = 4.04 V; Power = 96.9 W
4. V4 = 52*(27-24)*.95/24 = 6.175 V; Power = 148.2 W

The total generated output voltage will be:

50V + 51V +51V +52V + 2.02V +4.04V + 6.175V = 216.235V

And the total generated power produced will be:

216.235*24 = 5189.6 W

This is a significant improvement over the other schemes by using just 3 relatively small inexpensive DC-DC converters.