(54) **INPUT RAIL DYNAMIC POWER BALANCING AND MERGING**

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(57) **ABSTRACT**

A dynamic multiple input rail switching unit includes a plurality of DC input voltage rails and a rail switching section coupled to the plurality of DC input voltage rails that is configured to individually connect selected ones of the plurality of DC input voltage rails to a switched rail output. The dynamic multiple input rail switching unit also includes a rail selection section that is coupled to the rail switching section and configured to dynamically choose the selected ones by balancing rail supply currents from the plurality of DC input voltage rails based on rail supply current capacity margins and a switched rail output current. A dynamic multiple input rail switching unit operating method, and a dynamic multiple input rail power converter are also provided.
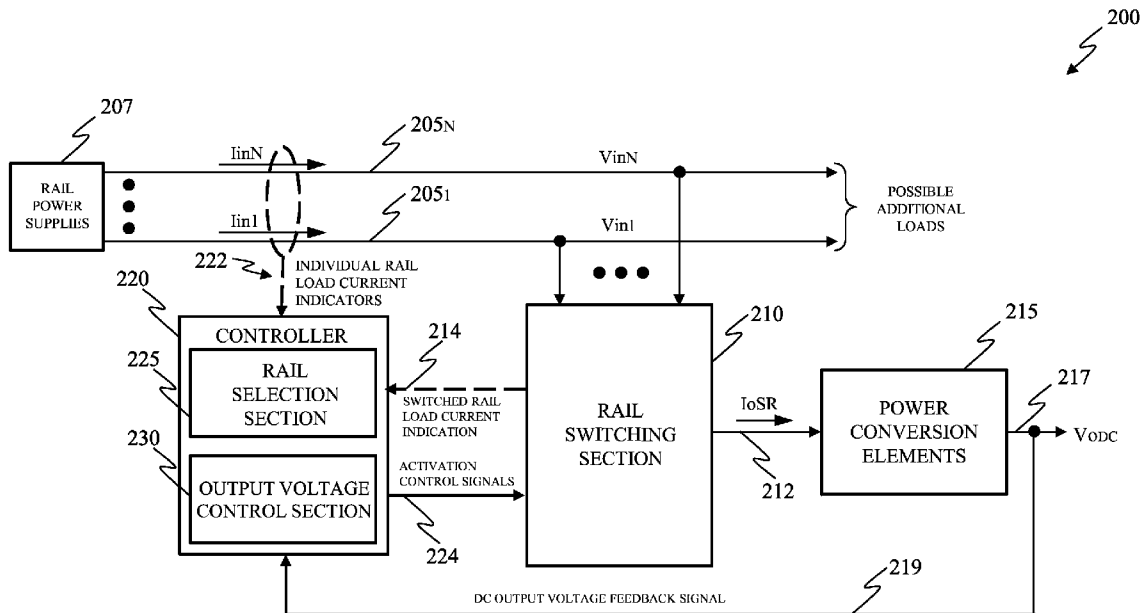
Fig. 1

200

207

RAIL POWER SUPPLIES

IinN
Iin1

205N
2051

VinN
Vin1

POSSIBLE ADDITIONAL LOADS

215

POWER CONVERSION ELEMENTS

217

VODC

219

INDIVIDUAL RAIL LOAD CURRENT INDICATORS

222

220 CONTROLLER

214

225 RAIL SELECTION SECTION

230 OUTPUT VOLTAGE CONTROL SECTION

SWITCHED RAIL LOAD CURRENT INDICATION
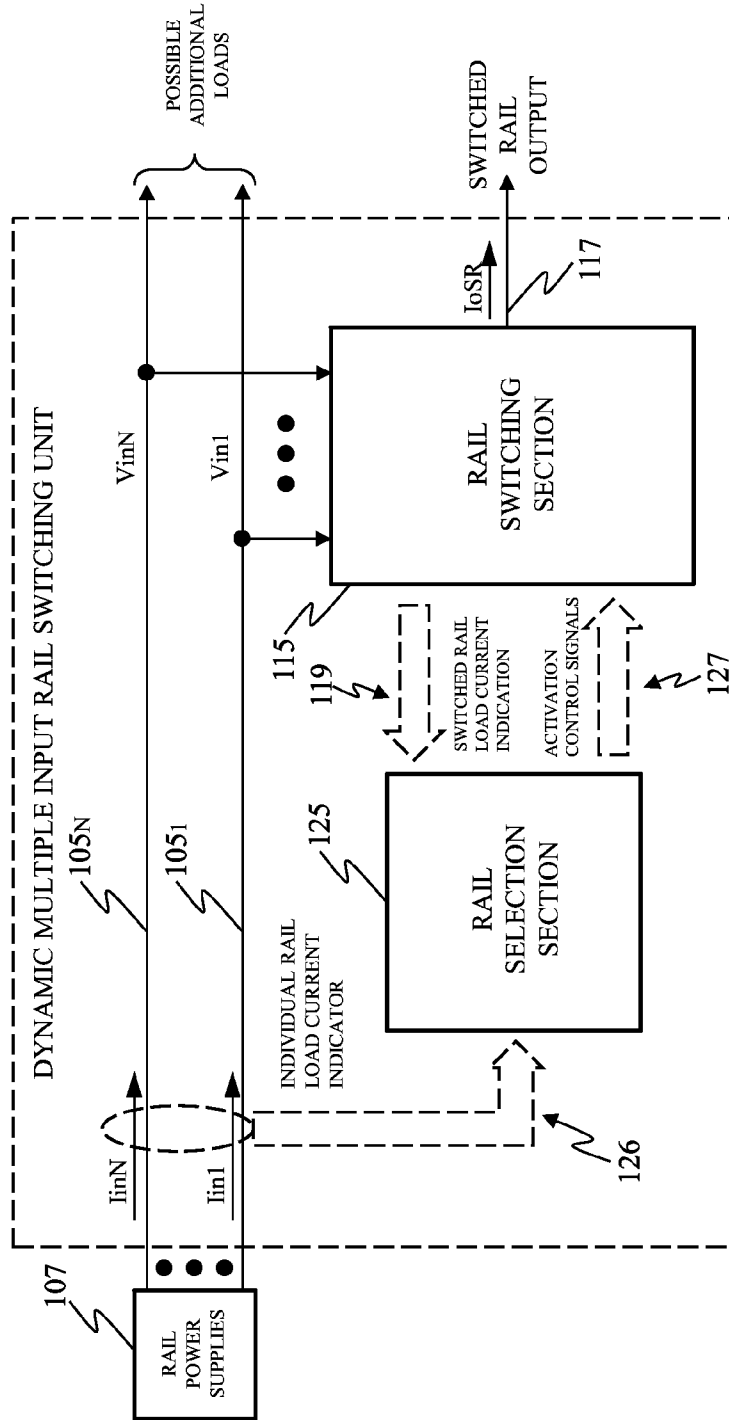
ACTIVATION CONTROL SIGNALS

224

210 RAIL SWITCHING SECTION

IoSR

212

DC OUTPUT VOLTAGE FEEDBACK SIGNAL

Fig. 2

Fig. 3

Fig. 4

500

505

START

510

PROVIDE
A PLURALITY OF DC INPUT VOLTAGE RAILS

515

CONNECT
INDIVIDUALLY SELECTED ONES OF THE PLURALITY OF
DC INPUT VOLTAGE RAILS TO A SWITCHED RAIL OUTPUT

520

CHOOSE DYNAMICALLY
THE SELECTED ONES BY BALANCING RAIL SUPPLY CURRENTS FROM
THE PLURALITY OF DC INPUT VOLTAGE RAILS BASED ON RAIL
SUPPLY CURRENT CAPACITY MARGINS AND
A SWITCHED RAIL OUTPUT CURRENT

525

END
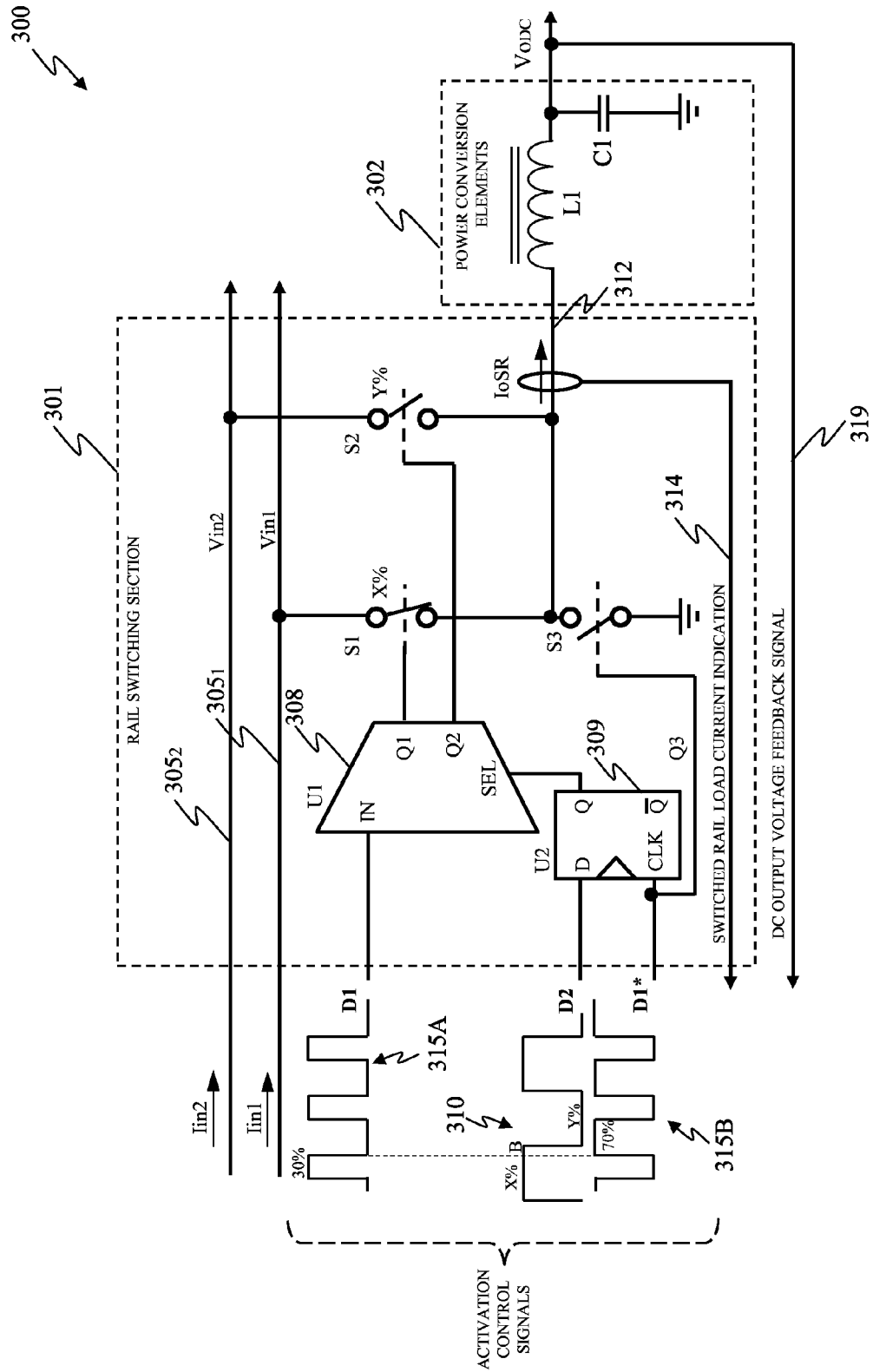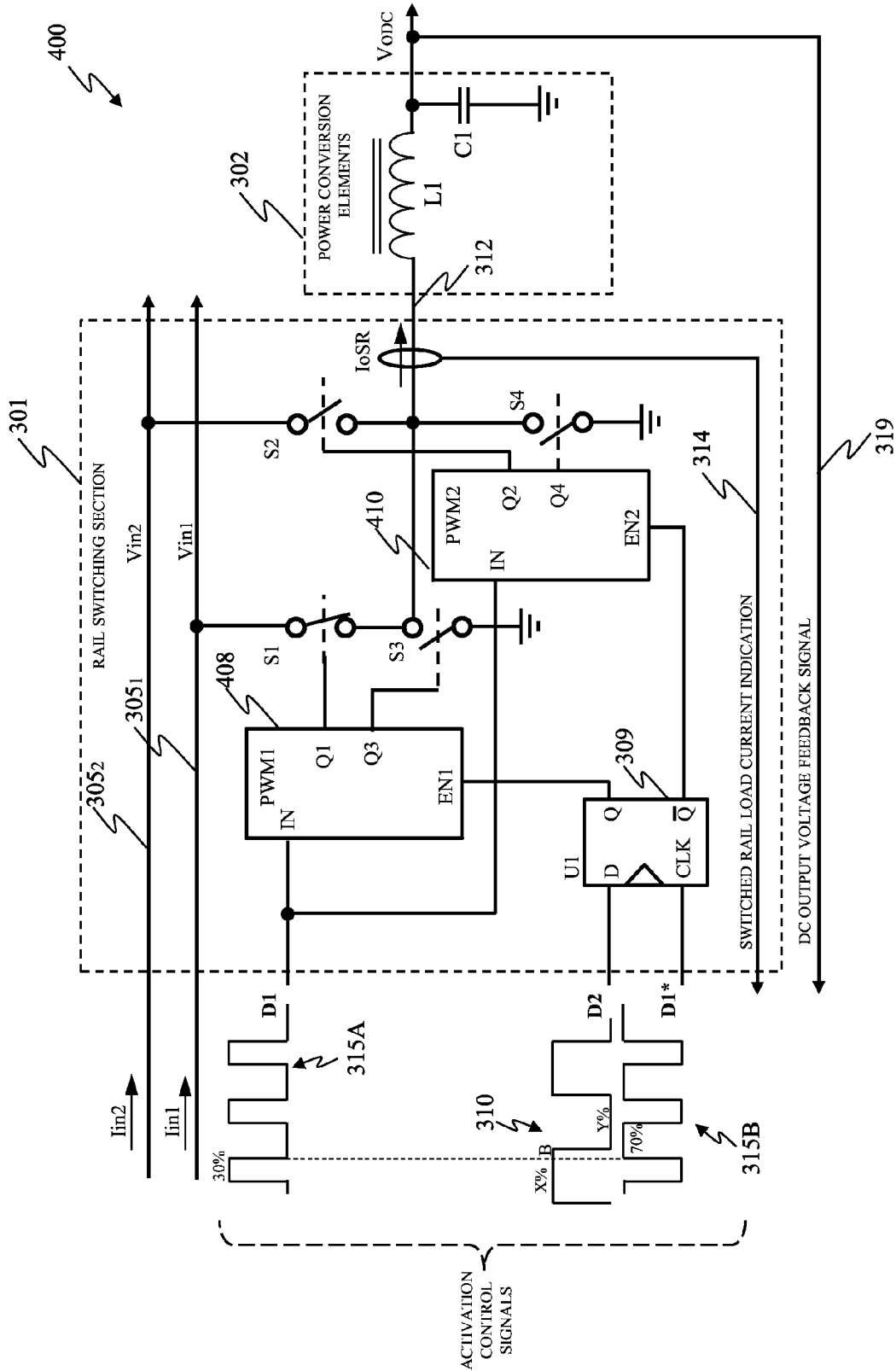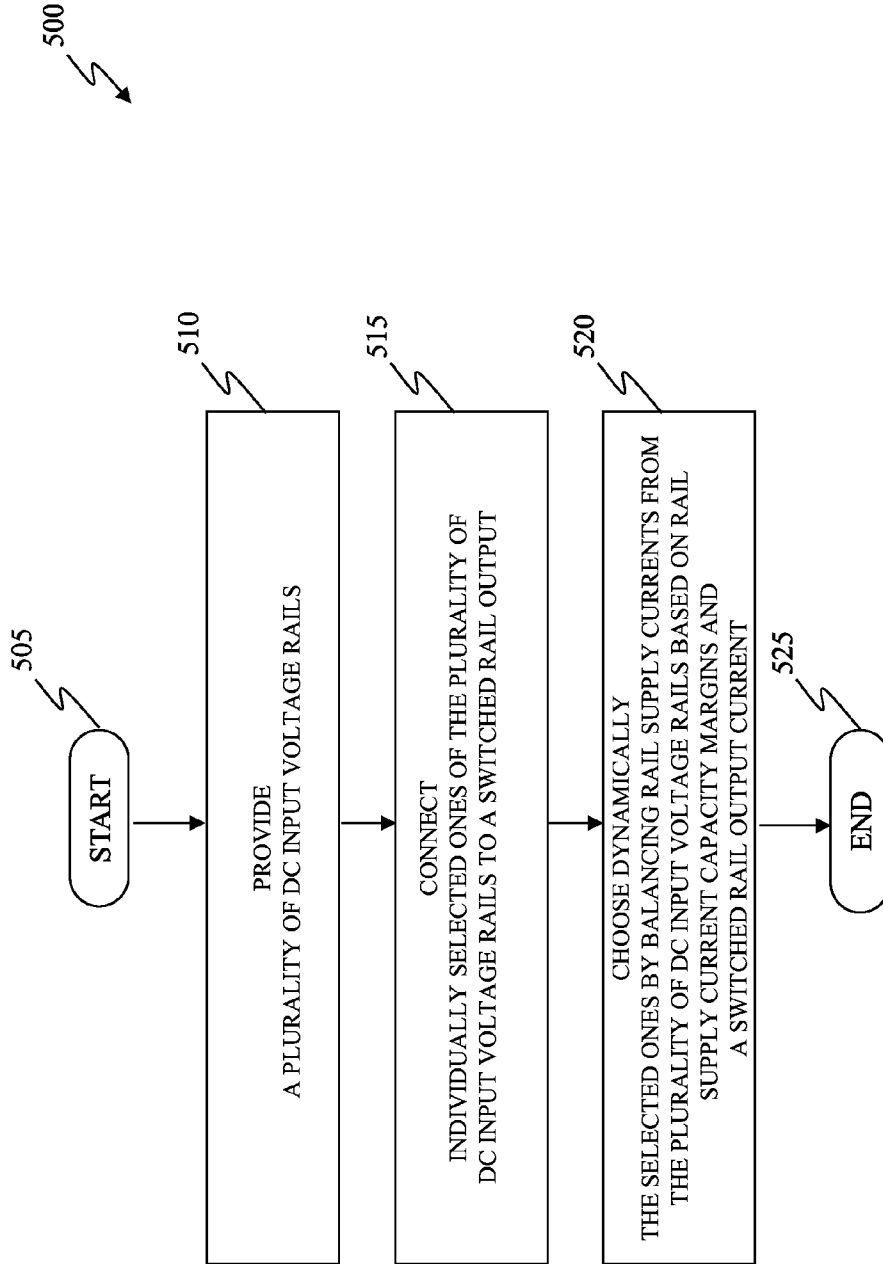
Fig. 5

INPUT RAIL DYNAMIC POWER BALANCING AND MERGING

TECHNICAL FIELD

[0001] This application is directed, in general, to power conversion and, more specifically, to a dynamic multiple input rail switching unit, a dynamic multiple input rail switching unit operating method and a dynamic multiple input rail power converter.

BACKGROUND

[0002] Input power balancing of applications employing multiple input rails is typically very challenging. This situation is very common in PCIe boards that provide more that watts of power and devices with redundant power supplies, such as servers. Currently, common approaches for load balancing are typically based on linear solutions, intermediate switched mode power supply (SMPS) converters or statically assigned current or power sharing. These solutions either incur power loss or do not allow the load sharing to be changed at run time. Improvements in this area would prove beneficial to the art.

SUMMARY

[0003] Embodiments of the present disclosure provide a dynamic multiple input rail switching unit, a dynamic multiple input rail switching unit operating method and a dynamic multiple input rail power converter.

[0004] In one embodiment, the dynamic multiple input rail switching unit includes a plurality of DC input voltage rails and a rail switching section coupled to the plurality of DC input voltage rails that is configured to individually connect selected ones of the plurality of DC input voltage rails to a switched rail output. The dynamic multiple input rail switching unit also includes a rail selection section that is coupled to the rail switching section and configured to dynamically choose the selected ones by balancing rail supply currents from the plurality of DC input voltage rails based on rail supply current capacity margins and a switched rail output current.

[0005] In another aspect, the dynamic multiple input rail switching unit operating method includes providing a plurality of DC input voltage rails and connecting individually selected ones of the plurality of DC input voltage rails to a switched rail output. The dynamic multiple input rail switching unit operating method also includes dynamically choosing the selected ones by balancing rail supply currents from the plurality of DC input voltage rails based on rail supply current capacity margins and a switched rail output current.

[0006] In yet another aspect, the dynamic multiple input rail power converter includes a plurality of DC input voltage rails and a rail switching section coupled to the plurality of DC input voltage rails that individually connects selected ones of the plurality of DC input voltage rails to a switched rail output, which is further connected to power conversion elements to provide a DC output voltage. The dynamic multiple input rail power converter also includes a rail selection section coupled to the rail switching section that dynamically chooses the selected ones by balancing rail supply currents from the plurality of DC input voltage rails based on rail supply current capacity margins and an input current of the power conversion elements and also includes an output volt-

age control section coupled to the rail selection section that provides regulation of the DC output voltage.

[0007] The foregoing has outlined preferred and alternative features of the present disclosure so that those skilled in the art may better understand the detailed description of the disclosure that follows. Additional features of the disclosure will be described hereinafter that form the subject of the claims of the disclosure. Those skilled in the art will appreciate that they can readily use the disclosed conception and specific embodiment as a basis for designing or modifying other structures for carrying out the same purposes of the present disclosure.

BRIEF DESCRIPTION

[0008] Reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0009] FIG. 1 illustrates a diagram of an embodiment of a dynamic multiple input rail switching unit constructed according to principles of the present disclosure;

[0010] FIG. 2 illustrates a diagram of an embodiment of a dynamic multiple input rail power converter constructed according to the principles of the present disclosure;

[0011] FIG. 3 illustrates a diagram of an example of a power converter output portion constructed according to the principles of the present disclosure;

[0012] FIG. 4 illustrates a diagram of another example of a power converter output portion constructed according to the principles of the present disclosure; and

[0013] FIG. 5 illustrates a flow diagram of an embodiment of a dynamic multiple input rail power converter operating method carried out according to the principles of the present disclosure.

DETAILED DESCRIPTION

[0014] Embodiments of the present disclosure allow a single output power rail to be connected to multiple input power rails and dynamically change the percentage of power drawn from each of the input rails. A general approach employs having multiple switching devices connected to the different input power rails such that input power sharing is achieved by varying an activation timing ratio among the different switching devices. Additionally, the approach allows added power conversion losses to be avoided when employed as a SMPS.

[0015] FIG. 1 illustrates a diagram of an embodiment of a dynamic multiple input rail switching unit, generally designated 100, constructed according to principles of the present disclosure. The multiple input rail switching unit 100 includes a plurality of DC input voltage rails 105_1-105_N, a rail switching section 115 and a rail selection section 125. The DC input voltage rails 105_1-105_N are connected to rail power supplies 107 to provide corresponding rail input voltages Vin1-VinN. As indicated, the DC input voltage rails 105_1-105_N may typically supply additional loads requiring current not employed by the rail switching section 115. Additionally, at least pairs of the plurality of DC input voltage rails 105_1-105_N provide a same DC voltage.

[0016] The rail switching section 115 is coupled to the plurality of DC input voltage rails 105_1-105_N and is configured to connect any one of the plurality of DC input voltage rails 105_1-105_N to a switched rail output 117 having a switched rail output (or load) current IoSR. The rail switching

section **115** may also provide a switched rail load current indication **119** of the switched rail load current IoSR. In some embodiments, the rail switching section **115** may accommodate disconnecting the switched rail output **117** from any of the DC input voltage rails **105**₁-**105**_N and connecting it to a ground or common return point of the rail power supplies **107**.

[0017] In the illustrated embodiment, the rail selection section **125** is coupled to the rail switching section **115** and is configured to direct switching between same-voltage ones of the plurality of DC input voltage rails **105**₁-**105**_N based on a rail current availability from each DC input voltage rail (generally, rail supply current capacity margins) and an output current requirement of the switched rail output **117**. The rail selection section **125** is configured to receive information on individual rail supply currents Iin1-IinN employing an individual rail load current indicator **126**. The rail selection section **125** also receives the switched rail load current indication **119** of the switched rail load current IoSR. Additionally, the rail selection section **125** provides activation control signals **127** to the rail switching unit **115** that activate switching therein required to connect a selected DC input voltage rail to the switched rail output **117**.

[0018] FIG. **2** illustrates a diagram of an embodiment of a multiple input rail power converter, generally designated **200**, constructed according to the principles of the present disclosure. The power converter **200** includes a plurality of DC input voltage rails **205**₁-**205**_N, a rail switching section **210**, power conversion elements **215** and a controller **220** having a rail selection section **225** and an output voltage control section **230**. The power converter **200** is generally constructed by adding the power conversion elements **215** and the output voltage control section **230** to the dynamic multiple input rail switching unit **100** of FIG. **1**.

[0019] The DC input voltage rails **205**₁-**205**_N are connected to rail power supplies **207** to provide corresponding rail input voltages Vin1-VinN, as before. In the illustrated embodiment, the rail switching section **210** may alternately connect a switched rail output **212**, between one of the DC input voltage rails **205**₁-**205**_N during a charging time of the power conversion elements **215** and alternately, to a ground or common return point of the rail power supplies **207**. The switched rail output **212** provides a switched rail load current IoSR, which is also an input load current for the power conversion elements **215**. The rail switching section **210** may also provide a switched rail load current indication **214** (power conversion elements input current) to the rail selection section **225** portion of the controller **220**, as before. The power conversion elements **215** correspond to the specific additional circuits or components required to convert a switched rail voltage on the switched rail output **212** into the converter output voltage VoDC.

[0020] Generally, the controller **220** provides activation control signals **224** to the rail switching section **210** that control proper selection timing and supply current balancing of the DC input voltage rails **205**₁-**205**_N, as well as control for maintaining a selected value of converter output voltage VoDC on a converter output **217**. Individual rail load current indicators **222** provide needed supply current loading information (Iin1-IinN) of each of the DC input voltage rails **205**₁-**205**_N for the rail selection section **225** and allow rail supply current balancing across same-voltage DC input voltage rails. The output voltage control section **230** employs a DC output voltage feedback signal **219** to provide another portion of the activation control signals **224** that maintains a

set-point for the output voltage VoDC as an output current varies due to loading changes on the converter output **217**.

[0021] FIG. **3** illustrates a diagram of an example of a power converter output portion, generally designated **300**, constructed according to the principles of the present disclosure. The power converter output portion **300** is representative of a buck converter and includes a rail switching section **301** and power conversion elements **302**. Additionally, switching elements illustrated in this embodiment are shown in a generic switch format. This generic switch format is employed to indicate that any switching element or device appropriate to an application and corresponding to the principles of the present disclosure may be employed.

[0022] For example, a single switching element, a group of series-connected switching elements, a group of parallel-connected switching elements or a combination of single, series-connected and parallel-connected switching elements may be employed. Additionally, solid state or semiconductor switching devices, optical switching devices or magnetic switching devices may also be employed. These devices may be either active switches (e.g., MOSFETS) or passive switches (e.g., diodes), as appropriate to a particular application.

[0023] The rail switching section **301** includes first and second rail switching elements S1, S2, a third switching element S3, a rail switching element selector **308** (U1) and a switching coordination unit **309** (U2). The first and second rail switching elements S1, S2 are respectively connected between first and second DC input voltage rails **305**₁, **305**₂ (that provide corresponding rail input voltages Vin1, Vin2) and a switched rail output **312** that is common to both. The switching element selector **308** determines which of the first and second rail switching elements S1, S2 is selected for activation. The third switching element S3 is activated to provide a synchronous switch for the buck converter when neither of the first and second rail switching elements S1, S2 is activated. The power conversion elements **302** include an inductor L1 and a capacitor C1 that are connected as shown to provide a converter output voltage VoDC.

[0024] In the illustrated example, activation control signals include first and second output voltage control signals **315A** (D1), **315B** (D1*) and an input voltage control signal **310** (D2). Here, D1* is the complement waveform of D1, as shown. The input voltage control signal **310** is provided by a rail selection section and the first and second output voltage control signals **315A**, **315B** are provided by an output voltage control section, which are not shown in FIG. **3**.

[0025] In some embodiments, a duty cycle of the input voltage control signal **310** may be determined solely by current margins available from the first and second voltage rails **305**₁, **305**₂ (i.e., load current conditions of Iin1, Iin2). Alternately, a switched rail load current indication **314** may be additionally employed by the associated rail selection section to facilitate selection between the first and second DC input voltage rails **305**₁, **305**₂.

[0026] For a first example of balancing rail supply currents employing the activation control signals (as shown in FIG. **3**), assume that the first and second voltage rails **305**₁, **305**₂ have a maximum load current capability of 75 A and each is delivering 50 A. That is, each has a rail supply current capacity margin of 25 A. Then, a supply current balance ratio (percentage) for each voltage rail may be calculated as:

$$\text{balance ratio} = (75 - 50) / [(75 - 50) + (75 - 50)] : \qquad (1)$$

$$(75 - 50) / [(75 - 50) + (75 - 50)]$$

$$= 50\% : 50\%,$$

which determines a duty cycle of 50% for the input voltage control signal **310**, under these conditions. This action balances the currents provided by the first and second voltage rails **305**$_1$, **305**$_2$.

[0027] As another example, assume that the first voltage rail **305**$_1$ is providing 75 A, the second voltage rail **305**$_2$ is providing only 50 A, and an additional 25 A is required. Since there is no additional current available from the first voltage rail **305**$_1$, the additional 25 A is taken from the second voltage rail **305**$_2$. For this example, the duty cycle of the input voltage control signal **310** becomes zero percent (0%), since the additional 25 A is provided solely from second voltage rail **305**$_2$. This, of course, again balances the currents drawn from the first and second voltage rails **305**$_1$, **305**$_2$.

[0028] The first output voltage control signal **315A** is employed to activate one or the other of the first and second rail switching elements **S1**, **S2** for a specific time period, which is dependent on the DC output voltage feedback signal **319** (i.e., VoDC). In the illustrated example, the first output voltage control signal **315A** has an activation time corresponding to a 30 percent duty cycle of its waveform. The second output voltage control signal **315B** has a 70 percent activation duty cycle, which is complementary to the first output voltage control signal **315A**. Here, it is employed to activate the switching element **S3** when neither of the first or second rail switching elements **S1**, **S2** is activated.

[0029] In this embodiment, the switching coordination unit **309** synchronizes the switching of input voltage control signal **310** and first and second output voltage control signals **315A**, **315B**. In the illustrated embodiment, the switching coordination unit **309** is a D flip-flop. The input voltage control signal **310** is connected to its D input, the second output voltage control signal **315B** is employed as a clock signal for the switching coordination unit **309**, and the Q output is connected to the switching element selector **308**, as shown. This arrangement ensures that the switching element selector **308** only switches when the first voltage control signal **315A** is not in its activating position (as noted by marker B).

[0030] Table 1 below provides a specific truth table for control of the first and second rail switching elements **S1**, **S2** and the third switching element **S3** as functions of the first output voltage control signal **315A** (D1) and the input voltage control signal **310** (D2).

TABLE 1

Switch Activation Table for FIG. 3				
D1	D2	Q1	Q2	Q3
1	1	1	0	0
1	0	0	1	0
0	1	0	0	1
0	0	0	0	1

[0031] As may be seen in Table 1, when D1 and D2 are true, the switching element selector output Q1 only activates the first rail switching element S1 (as indicated in FIG. 3). Similarly, when D1 is true and D2 is false, the switching element

selector output Q2 will only activate the second rail switching element S2. For all other D1, D2 conditions, only the third switching element S3 will be activated.

[0032] FIG. **4** illustrates a diagram of another example of a power converter output portion, generally designated **400**, constructed according to the principles of the present disclosure. The power converter output portion **400** provides a general structure and operation that mirrors the general structure and operation of the power converter output portion **300** discussed with respect to FIG. **3** above. Here, however, separate first and second switching element selectors **408**, **410** are employed to respectively control activation of separate switch pairs **S1:S3** and **S2:S4** as may be required in a particular application. Again, switching coordination between the activation control signals has been included to provide a lossless switching environment.

[0033] Table 2 below provides a specific truth table for control of the first and second rail switching elements **S1**, **S2** and the third and fourth switching elements **S3**, **S4** as functions of the first output voltage control signal **315A** (D1) and the input voltage control signal **310** (D2).

TABLE 2

Switch Activation Table for FIG. 4					
D1	D2	Q1	Q2	Q3	Q4
1	1	1	0	0	0
1	0	0	1	0	0
0	1	0	0	0	1
0	0	0	0	1	0

[0034] As may be seen in Table 2, when D1 and D2 are true, the switching element selector output Q1 only activates the first rail switching element S1 (as indicated in FIG. **4**). Similarly, when D1 is true and D2 is false, the switching element selector output Q2 will only activate the second rail switching element S2. Correspondingly, when D1 is false and D2 is true, only the fourth switching element S4 will be activated, and when D1 is false and D2 is false, only the third switching element S3 will be activated.

[0035] FIG. **5** illustrates a flow diagram of an embodiment of a dynamic multiple input rail switching unit operating method, generally designated **500**, carried out according to the principles of the present disclosure. The method **500** starts in a step **505**, and in a step **510**, a plurality of DC input voltage rails is provided. Then, individually selected ones of the plurality of DC input voltage rails are connected to a switched rail output, in a step **515**. The selected ones are chosen dynamically by balancing rail supply currents from the plurality of DC input voltage rails based on rail supply current capacity margins and a switched rail output current, in a step **520**.

[0036] In one embodiment, alternately connecting the switched rail output to a voltage common or ground point instead of to the selected ones of the plurality of DC input voltage rails is further included. In another embodiment, a reduction in switching power losses is provided by synchronously timing a switching between the plurality of DC input voltage rails and another switching for regulation of the switched rail output current. In yet another embodiment, a supply current balance ratio between the plurality of DC input voltage rails is dynamically determined at or during run time in response to changes in the rail supply current capacity margins or the switched rail output current. In still another

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embodiment, at least one of a rail supply current of each of the plurality of DC input voltage rails and the switched rail output current is monitored.

[0037] In a further embodiment, a routing of the selected ones of the plurality of DC input voltage rails to the switched rail output employs at least one selected from the group consisting of a single switch switching element, a group of series-connected switching elements, a group of parallel-connected switching elements and a combination of single, series-connected and parallel-connected switching elements. In yet a further embodiment, a routing of the selected ones of the plurality of DC input voltage rails to the switched rail output employs at least one selected from the group consisting of a solid state or a semiconductor switching device, an optical switching device and a magnetic switching device. The method 500 ends in a step 525.

[0038] While the method disclosed herein has been described and shown with reference to particular steps performed in a particular order, it will be understood that these steps may be combined, subdivided, or reordered to form an equivalent method without departing from the teachings of the present disclosure. Accordingly, unless specifically indicated herein, the order or the grouping of the steps is not a limitation of the present disclosure.

[0039] Those skilled in the art to which this application relates will appreciate that other and further additions, deletions, substitutions and modifications may be made to the described embodiments.

What is claimed is:

1. A dynamic multiple input rail switching unit, comprising:
   a plurality of DC input voltage rails;
   a rail switching section coupled to the plurality of DC input voltage rails and configured to individually connect selected ones of the plurality of DC input voltage rails to a switched rail output; and
   a rail selection section coupled to the rail switching section and configured to dynamically choose the selected ones by balancing rail supply currents from the plurality of DC input voltage rails based on rail supply current capacity margins and a switched rail output current.

2. The switching unit as recited in claim 1 wherein a reduction in switching power losses is provided by a synchronous timing of a switching between the plurality of DC input voltage rails and another switching for regulation of the switched rail output current.

3. The switching unit as recited in claim 1 wherein a supply current balance ratio between the plurality of DC input voltage rails is dynamically determined at or during run time in response to changes in the rail supply current capacity margins or the switched rail output current.

4. The switching unit as recited in claim 1 wherein at least one of a rail supply current of each of the plurality of DC input voltage rails and the switched rail output current is monitored.

5. The switching unit as recited in claim 1 wherein a routing of the selected ones of the plurality of DC input voltage rails to the switched rail output employs at least one selected from the group consisting of:
   a single switching element;
   a group of series-connected switching elements;
   a group of parallel-connected switching elements; and
   a combination of single, series-connected and parallel-connected switching elements.

6. The switching unit as recited in claim 1 wherein a routing of the selected ones of the plurality of DC input voltage rails to the switched rail output employs at least one selected from the group consisting of:
   a solid state or a semiconductor switching device;
   an optical switching device; and
   a magnetic switching device.

7. The switching unit as recited in claim 1 further configured to alternately connect the switched rail output to a voltage common or ground point instead of to the selected ones of the plurality of DC input voltage rails.

8. A dynamic multiple input rail switching unit operating method, comprising:
   providing a plurality of DC input voltage rails;
   connecting individually selected ones of the plurality of DC input voltage rails to a switched rail output; and
   choosing dynamically the selected ones by balancing rail supply currents from the plurality of DC input voltage rails based on rail supply current capacity margins and a switched rail output current.

9. The method as recited in claim 8 wherein a reduction in switching power losses is provided by a synchronous timing of a switching between the plurality of DC input voltage rails and another switching for regulation of the switched rail output current.

10. The method as recited in claim 8 wherein a supply current balance ratio between the plurality of DC input voltage rails is dynamically determined at or during run time in response to changes in the rail supply current capacity margins or the switched rail output current.

11. The method as recited in claim 8 wherein at least one of a rail supply current of each of the plurality of DC input voltage rails and the switched rail output current is monitored.

12. The method as recited in claim 8 wherein a routing of the selected ones of the plurality of DC input voltage rails to the switched rail output employs at least one selected from the group consisting of:
   a single switching element;
   a group of series-connected switching elements;
   a group of parallel-connected switching elements; and
   a combination of single, series-connected and parallel-connected switching elements.

13. The method as recited in claim 8 wherein a routing of the selected ones of the plurality of DC input voltage rails to the switched rail output employs at least one selected from the group consisting of:
   a solid state or a semiconductor switching device;
   an optical switching device; and
   a magnetic switching device.

14. The method as recited in claim 8 further including alternately connecting the switched rail output to a voltage common or ground point instead of to the selected ones of the plurality of DC input voltage rails.

15. A dynamic multiple input rail power converter, comprising:
   a plurality of DC input voltage rails;
   a rail switching section coupled to the plurality of DC input voltage rails that individually connects selected ones of the plurality of DC input voltage rails to a switched rail output, which is further connected to power conversion elements to provide a DC output voltage;
   a rail selection section coupled to the rail switching section that dynamically chooses the selected ones by balancing rail supply currents from the plurality of DC input volt-

age rails based on rail supply current capacity margins and an input current of the power conversion elements; and

an output voltage control section coupled to the rail selection section that provides regulation of the DC output voltage.

16. The power converter as recited in claim **15** wherein the power conversion elements form a buck converter to provide the DC output voltage.

17. The power converter as recited in claim **15** wherein a reduction in switching power losses is provided by a synchronous timing of a switching between the plurality of DC input voltage rails and another switching for regulation of the DC output voltage.

18. The power converter as recited in claim **15** wherein a supply current balance ratio between the plurality of DC input voltage rails is dynamically determined at or during run time in response to changes in the rail supply current capacity margins or the input current of the power conversion elements.

19. The power converter as recited in claim **15** wherein at least one of a rail supply current of each of the plurality of DC input voltage rails and the input current of the power conversion elements is monitored.

20. The power converter as recited in claim **15** further configured to alternately connect the switched rail output to a voltage common or ground point instead of to the selected ones of the plurality of DC input voltage rails.

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