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ADAPTIVE VOLTAGE CONVERSION FOR ENERGY EFFICIENT COMPUTING

ABSTRACT

A server rack may require DC voltages at various levels such as 12 volts, 1.8 volts, 1.2 volts, etc. that are suitable for different computing devices. In operation, a supply voltage is converted to the voltage required by corresponding computing devices. The voltage-level conversion is done in stages. A first stage converts from the supply voltage, e.g., 48 volts, to an intermediate voltage, e.g., in the range 7 to 15 volts. A second stage converts from the intermediate voltage to the appropriate output voltage. Efficiency of power conversion system varies with load, and depends on the intermediate voltage. This document describes techniques to measure conversion efficiency and adapt the intermediate voltage to optimize efficiency of power conversion system.

KEYWORDS

- Energy proportional computing
- Power Conversion
- Server rack power supply
- DC voltage conversion

BACKGROUND

A server rack is typically supplied with a voltage, e.g., 48 volts, that is higher than an operating voltage for components in the rack, e.g., 12 volts for storage trays, 1.8 volts for CPUs, 1.2 volts for memory, etc. Conversion from the higher supply voltage to the appropriate voltage for a computing device is accomplished by a power converter, e.g., a two-stage step down power converter. In an example scenario, a first stage may convert the input DC voltage from 48 volts to 12 volts, and a second stage may further step down from 12 volts to 1.8 volts.

The efficiency of power conversion depends on the output load and the intermediate voltage. For example, Fig. 1 shows representational efficiency vs. output load curves with different intermediate voltages. As seen in Fig. 1, if the intermediate voltage is 8 volts (solid line 102), efficiency peaks at a load of 30%, if the intermediate voltage is 10 volts (dashed line 104), efficiency peaks at a load of 50%, and if intermediate voltage is 12 volts (dashed-dot line 106), efficiency peaks at a load of 65%.

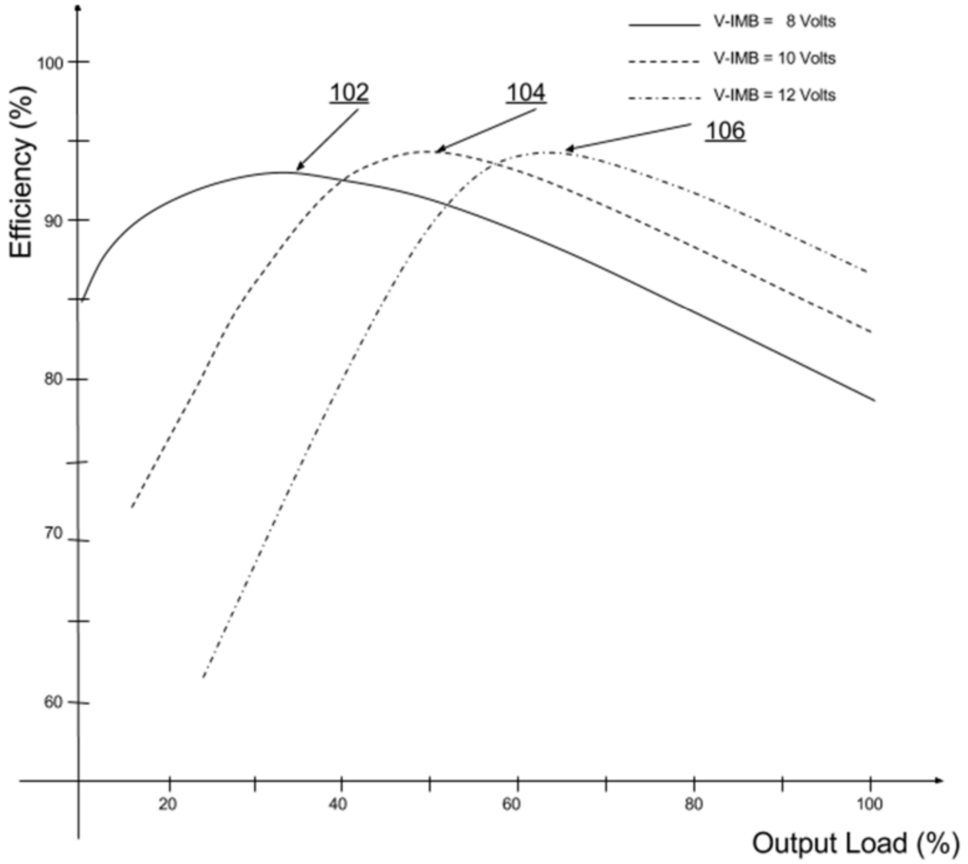

Fig. 1

An intermediate-voltage setting selected independent of load can result in lower overall efficiency. For example, referring again to Fig. 1, if power is supplied to a lightly loaded (25%) server rack, setting the intermediate voltage to 12 volts results in an efficiency of 62%, whereas setting the intermediate voltage to 8 volts results in an efficiency of 92%. Thus setting the intermediate voltage to 12 volts, rather than 8 volts, can result in an efficiency loss of 30 percentage points. In this same example scenario, if the load on the server rack is instead relatively high (90%), an intermediate-voltage setting of 8 volts, rather than 12 volts, can result in an efficiency loss of 10 percentage points.

DESCRIPTION

This document describes techniques to improve efficiency of power conversion by adapting the intermediate-voltage setting based on the instantaneous load.

Fig. 2 shows an example efficiency vs. load curve for a system that implements voltage conversion with the techniques described in this document. The thick line (202) in Fig. 2 represents efficiency that is at a nearly constant maximum, regardless of load, by appropriate selection of the intermediate voltage.

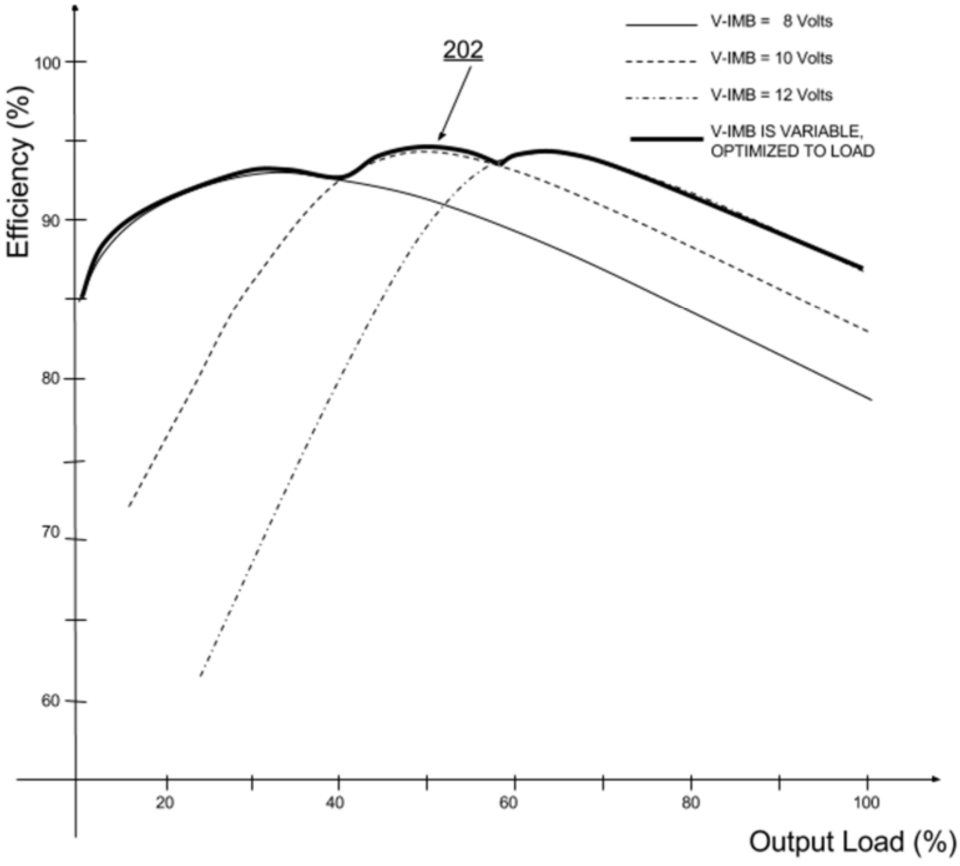

Fig. 2

Multi-Stage Power Conversion

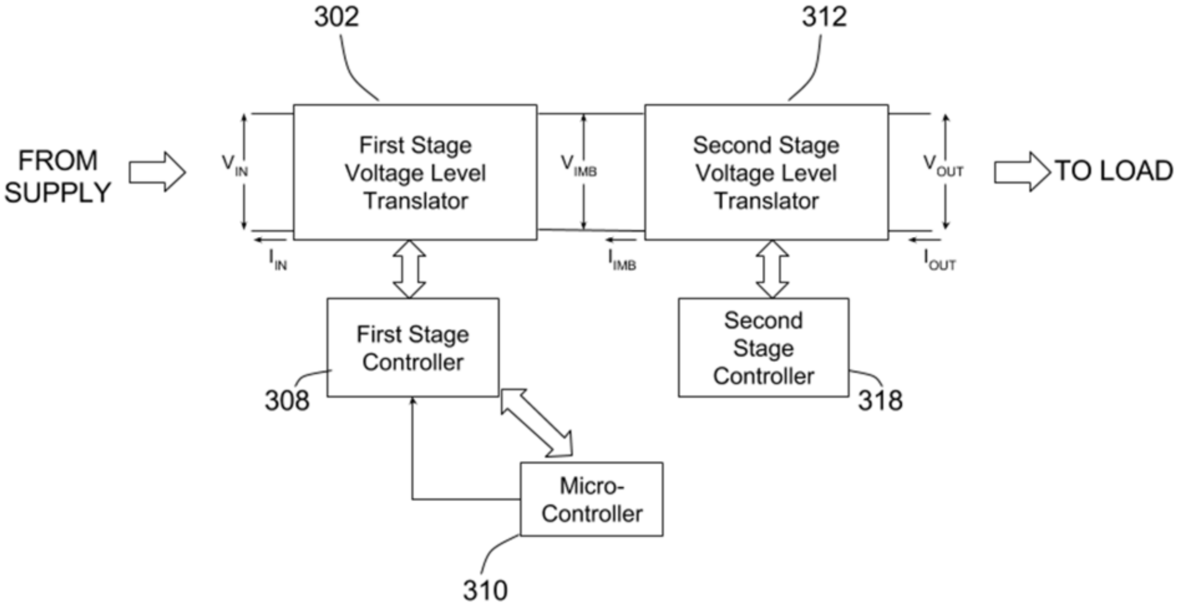

Fig. 3

Fig. 3 shows an example of two-stage power conversion. Two stages of power converters are shown, a first stage 302 and a second stage 312. The two stages are electrically coupled to each other. Each power converter is controlled by a respective controller, first stage controller 308 and second stage controller 318. Microcontroller 310 is coupled to the first stage controller 308. The microcontroller 310 is configured to send a control signal to first stage controller 308. While Fig. 3 shows two stages, techniques of this document can be applied to more than two stages.

The first stage voltage power converter 302 translates input voltage level V_{IN} to intermediate voltage V_{IMB}. The input voltage V_{IN} is supplied by a power supply, e.g., a power source that supplies power to a server rack. As shown in Fig. 3, the intermediate voltage V_{IMB} is of an intermediate bus between the two stages. The second stage voltage power converter 312 translates from the intermediate voltage V_{IMB} to output voltage V_{OUT}. The output voltage powers the load, e.g., a component of a server rack. Each of power converters 302 and 312 can be implemented with suitable power-conversion technologies and components such as, for example, switching regulator, phase shift full-bridge converter, DC transformer, LLC resonant circuit, etc.

In an example scenario, when the input voltage V_{IN} is 48 volts, the intermediate voltage V_{IMB} can be adjusted to a suitable value between 7 and 15 volts, and the output voltage V_{OUT} to 1.8 volts. Current drawn at the input to the first stage is denoted I_{IN}. Current drawn at the output of the second stage is denoted I_{OUT}. The current drawn at the input to the second stage is denoted I_{IMB}. Each stage is controlled by a respective controller, for example, the first stage 302 is controlled by a first stage controller 308, and the second stage is controlled by a second-stage controller 318.

The controllers 308 and 318 are configured to maintain a suitable voltage at the output of each stage as the load conditions change. For example, as load increases, current I_{OUT} increases, which may cause a momentary drop in voltage V_{OUT}. This drop in V_{OUT}, which may also cascade into a drop in V_{IMB}, is counteracted by controllers 308 and 318, as described below.

Operation

As load conditions change, the controllers 308 and 318 act to maintain the voltage at their respective outputs. However, as described earlier with reference to Fig. 1, one particular intermediate voltage cannot provide efficient operation across all varying load conditions. Adapting the intermediate voltage can improve efficiency. In the configuration shown in Fig. 3, Microcontroller 310 is configured to provide a value for the intermediate voltage to the first stage controller 308.

Microcontroller 310 senses present values for the input voltage V_{IN}, the input current I_{IN}, the output voltage V_{OUT} and output current I_{OUT} . Based on the sensed present values, the microcontroller calculates an operating efficiency. The microcontroller 310 calculates a new value for the intermediate voltage V_{IMB} and provides the value to the first stage controller 308. Calculation of the intermediate value is described below with reference to Fig. 4. The new value of the intermediate voltage differs from the previous value by a small amount, denoted V_{STEP}. For example, V_{STEP} may be 0.1 volts. Using this new value of the intermediate voltage, the microcontroller senses updated values for V_{IN}, I_{IN}, V_{OUT} and I_{OUT}.

The microcontroller then recalculates efficiency and determines if there is an improvement. Based respectively on whether or not there was an improvement, the microcontroller perturbs up or down the intermediate voltage by V_{STEP} volts. This process of perturbing intermediate voltage in a search for maximum efficiency is repeated, and ensures that the intermediate voltage is adapted based on the most recent load.

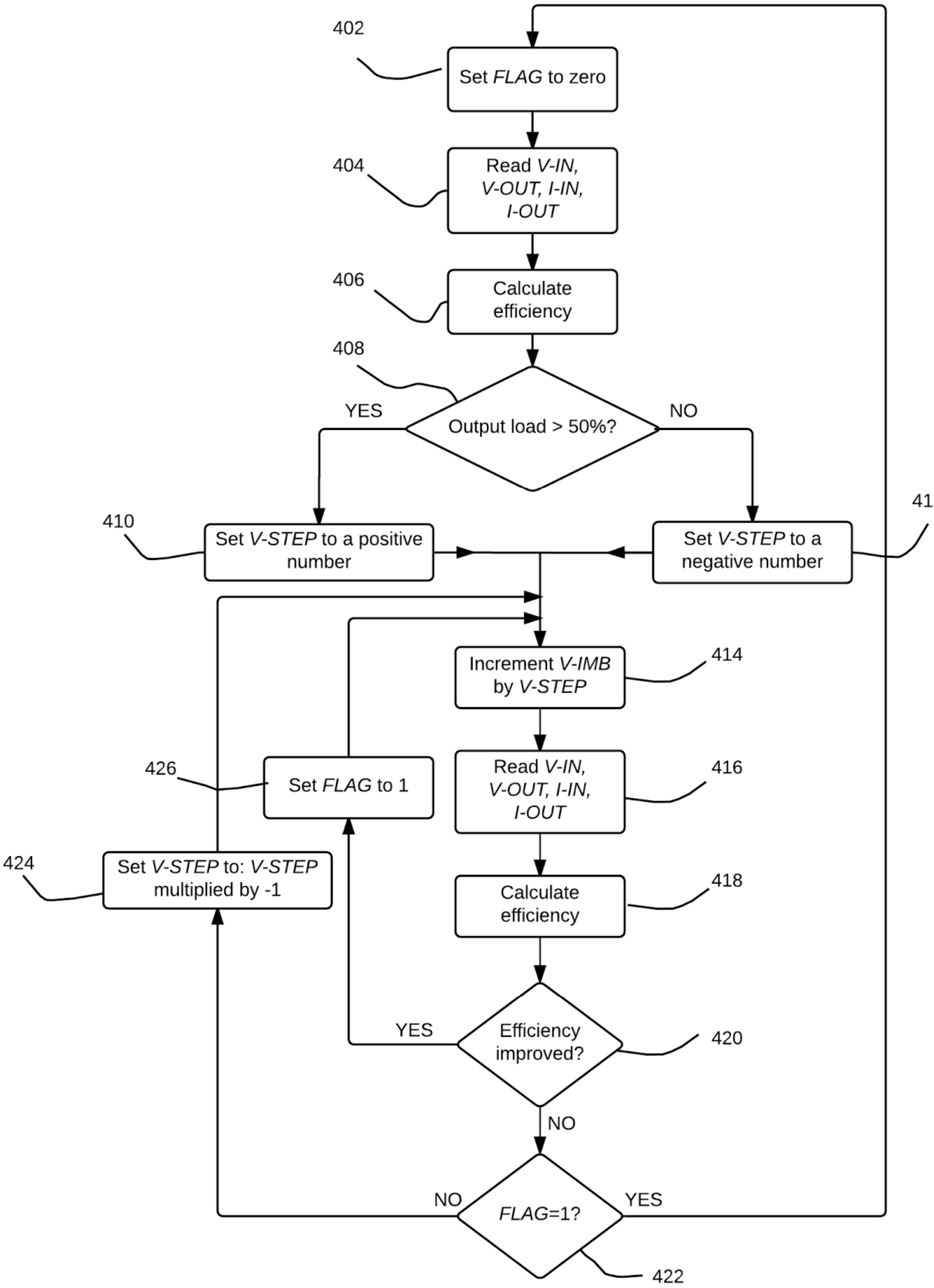
402
Set FLAG to zero
404
Read V-IN, V-OUT, I-IN, I-OUT
406
Calculate efficiency
408
Output load > 50%?
YES
NO
410
Set V-STEP to a positive number
412
Set V-STEP to a negative number
414
Increment V-IMB by V-STEP
426
Set FLAG to 1
416
Read V-IN, V-OUT, I-IN, I-OUT
424
Set V-STEP to: V-STEP multiplied by -1
418
Calculate efficiency
YES
Efficiency improved?
420
NO
NO
FLAG=1?
YES
422

Fig. 4

Fig. 4 illustrates an example process implemented by the microcontroller. Initially, a variable FLAG is set to zero (402). The value of FLAG influences the direction, positive or negative, of the perturbation in V_{IMB}. Initial values of V_{IN}, I_{IN}, V_{OUT} and I_{OUT} are read (404) and efficiency is calculated (406). Next, a decision is made (408) on the direction, positive or negative, of the perturbation V_{STEP}. If the output load is greater than 50% (or another suitable value selected based on the application), then V_{STEP} is set to a positive number (410), else V_{STEP} is set to a negative number (412). Following the setting of the sign of V_{STEP}, the the intermediate voltage is incremented (414) by V_{STEP}, the parameters V_{IN}, I_{IN}, V_{OUT}, and I_{OUT} are read (416), and efficiency is calculated (418).

If there is an improvement in efficiency (420), operations 414-420 are repeated with no change in sign of perturbation. The FLAG is set (426) to 1 which indicates that the direction of perturbation is unchanged. In case of a decrease in efficiency, the direction of perturbation is changed (424), that is, from positive to negative or vice-versa, e.g., by multiplying V_{STEP} by -1, and operations 414-420 are performed to perturb V_{IMB}, calculate efficiency and check for an improvement. In case of a decrease in efficiency (420) after more than one sequential increase in efficiency, indicated by a FLAG value of 1 at decision stage (422), the process continues to 402 to set FLAG to zero.

The process of Fig. 4 can be repeated periodically, e.g., once every second, to perturb the intermediate voltage V_{IMB} . For example, if V_{STEP}=0.1 volts, then V_{IMB} may change by 0.1 volts once every second. The process may be configured to clamp V_{IMB} so that it neither exceeds a preset maximum voltage, e.g., 14 volts, nor drops below a preset minimum voltage, e.g., 7.5 volts. While Fig. 4 shows an example process of adjustment of V_{IMB}, the adjustment can be performed using a suitable process of learning efficiency trends and adjusting the intermediate bus voltage.

Isolated Stages

The configuration shown in Fig. 3 is non-isolated multi-stage power conversion, that is, the two stages have a common electrical ground. In some examples, the two stages may not have a common electrical ground, that is, they may be electrically isolated from each other. Such a configuration with an isolated multi-stage power converter is shown in Fig. 5.

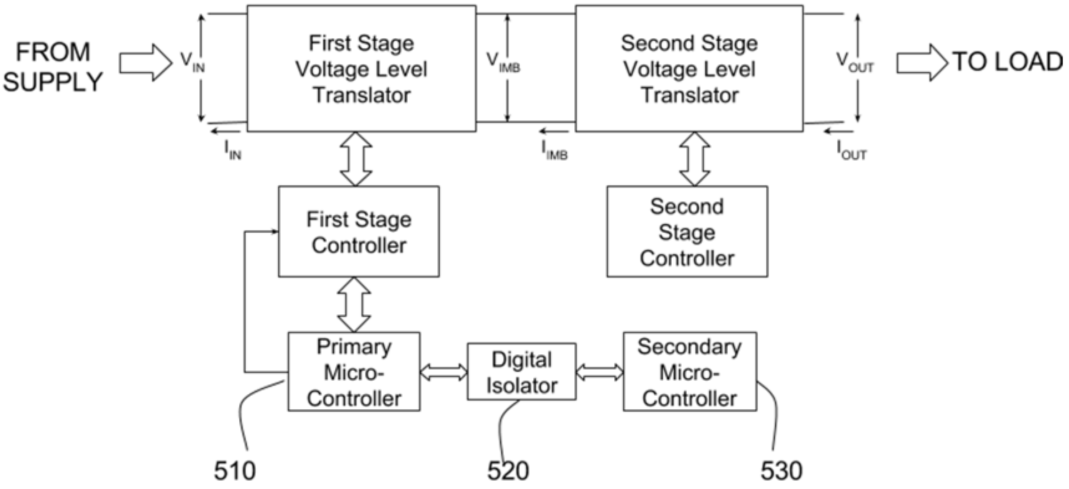

Fig. 5

In case of an isolated multistage power converter, each stage includes a dedicated microcontroller, shown as 510 and 530 respectively for the first and second stages. Microcontroller 510 senses V_{IN} and I_{IN}. Microcontroller 530 senses V_{OUT} and I_{OUT} . The values of V_{IN} and I_{IN} are passed to microcontroller 530 via a digital isolator 520. Microcontroller 530 executes the process of Fig. 4 and provides via digital isolator 520 and primary microcontroller 510 values for V_{IMB} to the first stage controller.

The techniques described here enable energy-efficient operation of server racks. Energy efficiency varies with load and depends on the intermediate voltage of a multi-stage power converter. By monitoring efficiency in real time and adapting the intermediate voltage, the techniques described herein continuously match the power supply to the load. This can ensure operation of the power converter at a nearly constant maximum efficiency irrespective of load. The techniques can be implemented without hardware modification. The techniques are suitable for various workloads, e.g., by optimizing the intermediate bus voltage based on the specific workload.