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CONTROL CIRCUIT AND METHOD FOR CONTROLLING A DC/DC CONVERTER

Abstract

A control circuit for controlling a power converter is provided. The control circuit is configured to operate the power converter in a PFM mode, using a set of activated PFM functional blocks, while a set of PWM functional blocks for operating the power converter in a PWM mode is inactive. Furthermore, the control circuit is configured, in preparation of a transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode, to enter a handover state, within which the power converter is operated in the PFM mode and one or more PWM functional blocks of the set of PWM functional blocks are activated.

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Background/Summary

TECHNICAL FIELD

[0001] The present document relates to a control circuit and a corresponding method for controlling a DC/DC converter.

BACKGROUND

[0002] A DC/DC converter may be operated in different operating modes of operation in order to optimize the efficiency of the converter across a wide range of input voltages and/or output load currents. For example, as illustrated in FIG. **1***a*, Pulse-Frequency Modulation (PFM) typically has a higher operating efficiency **101** for relatively low load currents **102** and continuous conduction modulation (CCM) typically has a higher operating efficiency **101** for relatively high load currents **102**. The optimum operating efficiency **101** may be achieved by operating the power converter in the PFM mode for load currents **102** that are at or below a pre-determined load current threshold and by operating the power converter in the CCM mode for load currents **102** that are above the pre-determined load current threshold.

[0003] It should be noted that Discontinuous Conduction Modulation (DCM) and Continuous Conduction Modulation (CCM) are examples for Pulse Width Modulation (PWM). The aspects outlined in the context of CCM operation are applicable to PWM operation in general.

[0004] FIG. **1***b* illustrates the operation of a power converter in PFM mode for relatively low load currents **102**. This allows the power switches of the power converter to be operated at a relatively low switching frequency **103**, thereby enabling an efficient operation of the power converter. Within the PFM mode, regulation of the output voltage of the power converter may be achieved by varying the switching frequency **103**.

[0005] As the load current **102** increases, the switching frequency **103** increases (up to a maximum frequency **109**, which may also be referred to as the PWM frequency), eventually triggering a mode transition from the PFM mode to the CCM mode (i.e. to the PWM mode). Within the PWM mode, regulation of the output voltage may be achieved by increasing the duty cycle of the one or more power switches of the power converter via pulse-width modulation.

[0006] The mode transition from the PFM mode to the PWM mode and the corresponding transition of the regulation scheme from PFM to PWM may impact the stability of regulation of the output voltage of the power converter. The present document addresses the technical problem of performing an efficient mode transition from the PFM mode to the PWM mode that ensures a stable regulation of the output voltage of the power converter. The technical problem is solved by the independent claims. Preferred examples are described in the dependent claims.

SUMMARY

[0007] According to an aspect, a control circuit for controlling a power converter is described. The control circuit is configured to operate the power converter in a pulse frequency modulation (PFM) mode, using a set of activated PFM functional blocks (of the control circuit), while a set of PWM functional blocks (of the control circuit) for operating the power converter in a pulse width modulation (PWM) mode is inactive. Furthermore, the control circuit is configured, in preparation of a transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode, to enter a handover state, within which the power converter is operated in the PFM mode, and within which one or more PMW functional blocks of the set of PWM functional blocks are activated (while one or more other PWM functional blocks of the set of PWM functional blocks are maintained inactive).

[0008] According to another aspect, a method for controlling a power converter is described. The method comprises operating the power converter in a PFM mode, using a set of activated PFM functional blocks, while a set of PWM functional blocks for operating the power converter in a PWM mode is inactive. Furthermore, the method comprises, in preparation of a transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode, entering a handover state, within which the power converter is operated in the PFM mode,

and within which one or more PWM functional blocks of the set of PWM functional blocks are activated.
[0009] It should be noted that the methods and systems including its preferred embodiments as outlined in the present document may be used stand-alone or in combination with the other methods and systems disclosed in this document. In addition, the features outlined in the context of a system are also applicable to a corresponding method. Furthermore, all aspects of the methods and systems outlined in the present document may be arbitrarily combined. In particular, the features of the claims may be combined with one another in an arbitrary manner.

Description

BRIEF DESCRIPTION OF THE FIGURES
[0010] The invention is explained below in an exemplary manner with reference to the accompanying drawings, wherein
[0011] FIG. **1***a* illustrates the operating efficiency of different operating modes of a power converter;
[0012] FIG. **1***b* illustrates a mode transition from PFM mode to CCM (i.e. PWM) mode;
[0013] FIG. **1***c* shows the level of the output voltage during a mode transition from PFM mode to CCM (i.e. PWM) mode;
[0014] FIG. **2** shows a converter system comprising a power converter and a control circuit for controlling the power converter;
[0015] FIG. **3***a* illustrates the generation of the ON-triggers and the OFF-triggers for controlling the high side switch of the power converter within the PFM mode;
[0016] FIG. **3***b* illustrates the generation of the ON-triggers and the OFF-triggers within the CCM (i.e. PWM) mode; and
[0017] FIG. **4** shows a flow chart of an example method for controlling a power converter.
DETAILED DESCRIPTION
[0018] As indicated above, the present document relates to providing a stable regulation of the output voltage of a DC/DC power converter during a mode transition from PFM mode to CCM mode (i.e. to PWM mode). The quality of regulation of the output voltage may notably be affected in case of a sudden dynamic load change which forces the power converter to switch modes rapidly.
[0019] FIG. **1***c* illustrates an example PFM-CCM transition which is triggered by a so-called panic comparator, wherein the panic comparator detects that the output voltage **125** (which is regulated to a given target voltage **126**) falls below a pre-determined panic threshold **127**.
[0020] One of the advantages of PFM operation is that it makes use of a relatively simple control scheme. As a result of this, many of the functional blocks of the control circuit of the power converter (which are used for operating the power converter in the CCM mode) may be placed in an inactive state while the power converter is operated in the PFM mode. As a result of this, the overall power consumption may be reduced.
[0021] During the transition from PFM mode to CCM mode, all the functional blocks which are required for the CCM mode are enabled and/or activated. However, due to the fact that these functional blocks had been deactivated within the PFM mode, the CCM mode starts operation with an unbiased regulation. As a result, the PFM-CCM transition may lead to a significant drop of the output voltage **125** (down to the level **128** indicated in FIG. **1***c*), since the regulation loop needs to first reach the output load current handover between the PFM mode and the CCM mode and then needs to reverse the output voltage drop.
[0022] FIG. **1***c* illustrates a transition from the PFM mode **112** to the CCM mode **111** which is caused by a sudden increase of the load current **123** (above the pre-determined transition threshold

124, which is used for performing a planned transition from the PFM mode **112** to the CCM mode **111**). The sudden increase of the load current **123** leads to a drop of the output voltage **125** that triggers the panic comparator (indicated by the panic pulse **121**), which causes an immediate transition to the CCM mode **111**.

[0023] FIG. **1***c* also illustrates how a sudden drop of the load current **123** within the CCM mode **112** may put the regulation into a sleep state (indicated by the pulse **122**).

[0024] As illustrated in FIG. **1***c*, the sudden transition from PFM mode **112** (with a relatively high voltage ripple) to the CCM mode **112** (which is a clocked operation using a fixed clock) may lead to a significant drop of the output voltage **125**. Furthermore, the panic threshold **127** is typically set to a voltage that is safely below the loop DC inaccuracy plus the ripple, such that the panic comparator is not trigged during normal operation. As a result of this, the panic comparator may be triggered relatively late (thereby further affecting the output voltage **125**).

[0025] FIG. **2** shows a block diagram of an example converter system **200** which comprises a power converter **210**, **220**, notably a buck converter **210** and a boost converter **220** with an inductor **201**, each converter **210**, **220** comprising driver circuitry **211**, **212**, **213**, **221**, **222**, **223**. The system **200** further comprises a control circuit **230**, wherein the control circuit **230** comprises [0026] one or more PFM functional blocks **232**, **253**, which are only needed for the PFM mode **112**; [0027] one or more PWM functional blocks **253**, **254**, **256**, **257**, **258**, **259**, **260**, which are only needed for the PWM (notably the CCM) mode **111**; and [0028] one or more common function blocks **234**, **233**, **235**, **236**, **240**, **241**, **251**, which may be used jointly for the PFM mode **112** and the PWM mode **111**.

[0029] FIG. **3***a* illustrates the inductor current **301** (through the inductor **201**) and the output voltage **125** as a function of time, within the PFM mode **112**. The control circuit **230** is configured to repeatedly generate [0030] an ON-trigger **304** for causing the one or more high-side switches of the power converter **210**, **220** to turn on (and for causing the one or more low-side switches of the power converter **210**, **220** to turn off); and [0031] an OFF-trigger **306** for causing the one or more high-side switches of the power converter **210**, **220** to turn off (and for causing the one or more low-side switches of the power converter **210**, **220** to turn on).

[0032] Within the PFM mode **112**, the output voltage **125** may be compared with a pre-determined voltage threshold **302** (which is typically lower than the target voltage **126**, **252** for the output voltage **125** and/or higher than the panic threshold **127**). When the output voltage **125** reaches and/or falls below the pre-determined voltage threshold **302** (which may be detected by the PFM functional block **253**), an ON-trigger **304** may be generated.

[0033] Once the one or more high-side switches of the power converter **210**, **220** are turned on, the inductor current **301** increases. The inductor current **301** may be compared to a pre-determined (fixed) current threshold **305** (within the PFM functional block **232**). The OFF-trigger **306** may be generated, when the inductor current **301** reaches the pre-determined current threshold **305**.

[0034] Once the one or more high-side switches of the power converter **210**, **220** are turned off, the inductor current **301** decreases and eventually falls to zero (at time instant **307**). This causes the output voltage **125** to drop, which will eventually cause the generation of a subsequent ON-trigger **304**.

[0035] An increase of the load current **123** causes the output voltage **125** to drop faster, thereby causing the subsequent ON-trigger **304** to be generated more rapidly, i.e. thereby increasing the switching frequency **103** of the one or more high-side switches of the power converter **210**, **220**. Eventually, the time gap **308** between the time instant **307** at which the inductor current **301** falls to zero and the subsequent ON-trigger **304** falls to zero, such that the maximum switching frequency **109** of the PFM mode **112** (which may be equal to the PWM frequency) is reached.

[0036] FIG. **3***b* illustrates the inductor current **301** as a function of time within the PWM mode **111**. Within the PWM mode **111** the ON-triggers **304** are generated using a fixed clock signal (which is provided by the PWM functional block **257**, possibly in conjunction with the PWM functional blocks **258**, **259**). The OFF-triggers **306** are generated by comparing the inductor current **301** with an adaptive peak current threshold **315**. The comparison may be performed within the PWM functional block **256**. An OFF-trigger **306** may be generated when the inductor current **301** reaches the adaptive peak current threshold **315**.

[0037] The adaptive peak current threshold **315** may be dependent on the error voltage which is indicative of the deviation of the output voltage **125** from the target voltage **126**, **252** (which is provided e.g. by a digital-to-analog converter **251**). The error voltage may be generated by the PWM functional blocks **253**, **254**.

[0038] Additional function blocks of the control circuit **230** may be [0039] a PWM functional block **255** for generating a ramp signal (which is typically used for generating the OFF-triggers **306**); [0040] a PWM functional block **260** for detecting a sleep demand (for putting the PWM regulation into sleep); [0041] a common functional block **241** for short circuit protection; [0042] one or more common functional blocks **235**, **236** for zero cross detection; [0043] a common functional block **234** for generating an OFF-trigger **306**; [0044] a common functional block **233** for generating an ON-trigger **304**; and/or [0045] a common functional block **240** for logic operations.

[0046] The control circuit **230** may be configured to operate within a handover state for preparing a transition from the PFM mode **112** to the PWM mode **111**. Within the handover state, the power converter **210**, **220** is operated within the PFM mode **112**, such that the PFM functional blocks and the common functional blocks are active. Furthermore, a subset of the PWM functional blocks may be activated for pre-biasing the subsequent PWM based regulation. In particular, [0047] the one or more PWM functional blocks **253**, **254** for generating the error voltage may be activated, in order to ensure that the adaptive peak current threshold **315** is at a correct level, when the power converter **210**, **220** starts operating within the PWM mode **111**; and/or [0048] the PWM functional block **256** for comparing the inductor current **301** to the adaptive peak current threshold **315** may be activated, in order to ensure that the comparator is in a settled state, when the power converter **210**, **220** starts operating within the PWM mode **111**.

[0049] On the other hand, one or more other PWM functional blocks may remain inactive during the handover state, e.g., [0050] the PWM functional block **255** for generating the ramp signal; [0051] the PWM functional block **260** for detecting a sleep demand; and/or [0052] the one or more functional blocks **257**, **258**, **259** for generating the clock signal.

[0053] The control circuit **230**, e.g. the logic block **240**, may be configured to detect that a handover condition for entering the handover state is met. In reaction to this, the control circuit **230** may be put into the handover state, while maintaining operation of the power converter **210**, **220** within the PFM mode **112**. The actual transition to the PWM mode **111** may be triggered [0054] by the fact that the switching frequency **103** reaches the maximum frequency **109**; [0055] by the fact that the load current **123** exceeds the load current threshold **124**; and/or [0056] by the fact that the panic comparator is triggered.

[0057] In view of the fact that the control circuit **230** has been prepared for the PWM mode **111** within the handover state, the drop of the output voltage **125** may be substantially reduced.

[0058] An example condition for entering the handover state may be the fact that the switching frequency **103** reaches a pre-determined handover frequency **105** (as illustrated in FIG. **1***b*). By consequence, the handover state **108** may be provided for switching frequencies **103** between the handover frequency **105** and the maximum frequency **109**.

[0059] Hence, a control of a multi-mode power converter **210**, **220** is described, for which the delay time of the transition between PFM and PWM control is reduced. Specifically, while still operating in PFM mode **112**, one or more functional blocks needed for the PWM mode **111** may be pre-biased in anticipation of a PFM to PWM transition.

[0060] In other words, a third operating mode, in addition to the PFM and PWM mode, is described. This third operating mode is a handover state **108** for a transition from PFM to PWM operation (i.e. from relatively small to relatively high load currents **102**). The handover state **108** operates the converter **210**, **220** in PFM operation, while at the same time causing a pre-bias of one or more functional blocks which are needed in PWM operation. The handover state **108** may be initiated once the PFM mode load current capability is about to reach its maximum, while the converter DC voltage regulation is not yet lost.

[0061] Once the one or more PWM functional blocks are enabled, the one or more PWM functional blocks operate in parallel to the PFM operation of the converter **210**, **220**. The control outputs of the one or more PWM functional blocks are ignored as long as the PFM mode **112** is able to support the output load current **102**. Once the PFM mode **112** reaches its maximum output load capability and the output load continues to increase, DC regulation is violated and the output voltage **125** starts to drop. The drop of the output voltage **125** leads to an increased controller error signal (i.e. an increased error voltage) which causes the PWM functional blocks to reverse the output voltage drop by regulating to an increased peak current (i.e. to an increased adaptive peak current threshold **315**).

[0062] The actual transition from PFM operation to PWM operation during the handover state **108** may be caused at the moment when the one or more PWM functional blocks regulate to a higher peak current **315** than the current **305** which is provided by the PFM operation. As a result of this, the output of the one or more PWM functional blocks is not ignored anymore, but is used for the actual transition. As a result of this, a smooth handover between the PFM and the PWM modes may be achieved.

[0063] One or more input factors may be used as conditions for initiating the handover state **108**. Example input factors are: the PFM operating frequency **103**, the number of PFM pulses prior to an idle period, the input voltage and/or the output current. A condition for entering the handover state **108** may be defined based on one or more of these input factors.

[0064] The control circuit **230** may be configured to anticipate a transition to the PWM mode **111**, when the switching frequency **103** approaches the PWM switching frequency **109**. When the PFM switching frequency **103** exceeds a pre-determined PWM sub-block pre-bias threshold **105**, one or more of the PWM functional blocks may be pre-biased (within the handover state **108**), in preparation for the PFM to PWM transition. This reduces the control delay when the transition actually occurs, thereby reducing disruptions within the output voltage **125**.

[0065] In view of the fact, that the output load current **102** is relatively high at the transition from PFM to PWM, the activation of the one or more PWM functional blocks does not substantially affect the efficiency of the power converter **210**, **220**.

[0066] As indicated above, when operating the power converter **210**, **220** in the handover state **108**, the actual mode transition from PFM mode **112** to PWM mode **111** may be caused automatically, once the adaptive peak current threshold **315** (used within the PWM mode **111**) reaches and/or exceeds the current threshold **305** (used within the PFM mode **112**).

[0067] FIG. **4** shows a flow chart of a (possibly computer-implemented) method **400** for controlling a power converter **210**, **220** (notably a switched-mode power converter **210**, **220**, such as a buck, a boost or a buck-boost converter). The method **400** comprises operating **401** the power converter **210**, **220** in a PFM mode **112**, using a set of activated PFM functional blocks **231**, **232**, while a set of PWM functional blocks **253**, **254**, **255**, **256**, **257**, **258**, **259**, **260** for operating the power converter **210**, **220** in a pulse width modulation, PWM, mode **111** is inactive. As a result of this, a power efficient operation of the power converter **210**, **220** (at relatively low load currents **102**) is achieved.

[0068] The method **400** further comprises, in preparation of a transition from operating the power converter **210**, **220** in the PFM mode **112** to operating the power converter **210**, **220** in the PWM mode **111**, entering **402** a handover state **108**, within which the power converter **210**, **220** is still operated in the PFM mode **112** (and not yet operated in the PWM mode **111**). However, one or more PWM functional blocks **253**, **254**, **256** (notably a subset) of the set of PWM functional blocks **253**, **254**, **255**, **256**, **257**, **258**, **259**, **260** are activated within the handover state **108** (without taking into account the signals which are generated by the one or more activated PWM functional blocks **253**, **254**, **256** for performing the actual operation of the power converter **210**, **220**, notably for performing the actual regulation of the output voltage **124** of the power converter **210**, **220**). As a result of this, a power efficient, stable and smooth transition to the PWM mode **111** may be performed.

[0069] Hence, a control circuit **230** for controlling a power converter **210**, **220** (notably a switched mode power converter **210**, **220**) is described. The control circuit **230** is configured to operate the power converter **210**, **220** in a PFM mode **112**, using a set of activated PFM functional blocks **231**, **232**, while a set of PWM functional blocks **253**, **254**, **255**, **256**, **257**, **258**, **259**, **260** for operating the power converter **210**, **220** in a PWM mode **111** (notably a CCM or DCM mode) is inactive. As a result of this, the power consumption of the set of PWM functional blocks **253**, **254**, **255**, **256**, **257**, **258**, **259**, **260** can be reduced (possibly to zero).

[0070] When operating the power converter **210**, **220** in the PWM mode **111**, the set of PFM functional blocks **231**, **232** may be deactivated and the set of PWM functional blocks **253**, **254**, **255**, **256**, **257**, **258**, **259**, **260** may be activated.

[0071] The control circuit **230** is further configured, in preparation of a transition from operating the power converter **210**, **220** in the PFM mode **112** to operating the power converter **210**, **220** in the PWM mode **111**, to enter a handover state **108**, within which the power converter **210**, **220** is still operated in the PFM mode **112**. However, one or more PWM functional blocks **253**, **254**, **256** (notably a subset) of the set of PWM functional blocks **253**, **254**, **255**, **256**, **257**, **258**, **259**, **260** may be activated within the handover state **108**, thereby preparing a smooth transition to the PWM mode **111**.

[0072] The one or more PWM functional blocks **253**, **254**, **256** which are activated in the handover state **108** may be configured to determine the deviation of the output voltage **125** of the power converter **210**, **220** from a target voltage **126**, **252**. In particular, the one or more PWM functional blocks **253**, **254**, **256** may be configured to determine an error voltage. Alternatively, or in addition, the one or more PWM functional blocks **253**, **254**, **256** which are activated in the handover state **108** may be configured to determine an adaptive peak current threshold **315** which is used for generating a trigger **306** (notably an OFF-trigger) for turning on or off (notably for turning off) a (high side) power switch of the power converter **210**, **220**. The adaptive peak current threshold **315** may be dependent on the deviation of the output voltage **125** of the power converter **210**, **220** from the target voltage **252** (notably the adaptive peak current threshold **315** may be dependent on the error voltage).

[0073] Alternatively, or in addition, the one or more PWM functional blocks **253**, **254**, **256** which are activated in the handover state **108** may be configured to compare the inductor current **301** through the inductor **201** of the power converter **210**, **220** with the (adaptive) peak current threshold **315** for generating a trigger **306** for turning on or off a power switch of the power converter **210**, **220**.

[0074] By activating the above-mentioned one or more PWM functional blocks **253**, **254**, **256** a particularly smooth transition to the PWM mode **111** may be achieved.

[0075] The control circuit **230** may be configured to maintain one or more PWM functional blocks **255**, **257**, **258**, **259**, **260** of the set of PWM functional blocks **253**, **254**, **255**, **256**, **257**, **258**, **259**, **260** deactivated within the handover state **108**. The one or more PWM functional blocks **255**, **257**, **258**, **259**, **260** which are maintained deactivated within the handover state **108** may comprise, [0076] one or more PWM functional blocks **257**, **258**, **259** for generating a clock signal; [0077] one or more PWM functional blocks **255** for generating a ramp signal; and/or [0078] one or more PWM functional blocks **266** for detecting that the power converter **210**, **220** may be put into a sleep condition.

[0079] By maintaining one or more PWM functional blocks **255**, **257**, **258**, **259**, **260** deactivated within the handover state **108**, the efficiency of the power converter **210**, **220** may be increased.

[0080] The control circuit **230** may be configured to determine that a handover condition for entering the handover state **108** is met. The handover condition **108** may be dependent on, [0081] the switching frequency **103** at which the power converter **210**, **220** is operated within the PFM mode **112**; and/or [0082] the load current **123** which is provided at the output of the power converter **210**, **220**; and/or [0083] the input voltage and/or the output voltage **125** of the power converter **210**, **220**.
[0084] The control circuit **230** may be configured to enter the handover state **108**, in reaction to determining that the handover condition is met, thereby providing a particularly reliable control of the power converter **210**, **220**.
[0085] The control circuit **230** may be configured to determine (subsequently to entering the handover state **108**) that the handover condition is not met anymore. In reaction to determining that the handover condition is not met anymore, the one or more PWM functional blocks **253**, **254**, **256** which had been activated within the handover state **108** may be deactivated. Furthermore, the power converter **210**, **220** may be operated in the PFM mode **112**, using the set of activated PFM functional blocks **231**, **232**, while the set of PWM functional blocks **253**, **254**, **255**, **256**, **257**, **258**, **259**, **260** for operating the PWM mode **111** is inactive.
[0086] Hence, the control circuit **230** may be configured to revert back to the pure PFM mode **112** in a reliable manner.
[0087] The control circuit **230** may be configured to compare the inductor current **301** with a fixed current threshold **305** when operating the power converter **210**, **220** in the PFM mode **112** to generate an OFF-trigger **306** for turning off one or more (high side) switches of the power converter **210**, **220**. Furthermore, the control circuit **230** may be configured to compare the inductor current **301** with the adaptive peak current threshold **315** when operating the power converter **210**, **220** in the PFM mode **112** to generate an OFF-trigger **306** for turning off the one or more (high side) switches of the power converter **210**, **220**.
[0088] In addition, the control circuit **230** may be configured to perform the transition from operating the power converter **210**, **220** in the PFM mode **112** to operating the power converter **210**, **220** in the PWM mode **111** in dependence of the fixed current threshold **305** and the adaptive current threshold **315**. In particular, the control circuit **230** may be configured to compare the adaptive current threshold **315** with the fixed current threshold **305**. The transition from operating the power converter **210**, **220** in the PFM mode **112** to operating the power converter **210**, **220** in the PWM mode **111** may be performed, if (notably as soon as) the adaptive current threshold **315** reaches or exceeds the fixed current threshold **305**.
[0089] The control circuit **230** may be configured to determine the adaptive peak current threshold **315** within the handover state **108** using the one or more activated PWM functional blocks **253**, **254**, **256**. As a result of this, a particularly smooth transition from the PFM mode **112** to the PWM mode **111** may be performed.
[0090] The control circuit **230** may be configured to, in the context of the transition from operating the power converter **210**, **220** in the PFM mode **112** to operating the power converter **210**, **220** in the PWM mode **111**, activate the one or more PWM functional blocks **255**, **257**, **258**, **259**, **260** from the set of PWM functional blocks **253**, **254**, **255**, **256**, **257**, **258**, **259**, **260** that had not been activated in the handover state **108**. Furthermore, the set of PFM functional blocks **231**, **232** may be deactivated. As a result of this, a particularly smooth transition from the PFM mode **112** to the PWM mode **111** may be performed.
[0091] Furthermore, a power converter system **200** is described which comprises a power converter **210**, **220** and the control circuit **230** for controlling the power converter **210**, **220**.
[0092] It should be noted that the description and drawings merely illustrate the principles of the proposed methods and systems. Those skilled in the art will be able to implement various arrangements that, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope. Furthermore, all examples and embodiment

outlined in the present document are principally intended expressly to be only for explanatory purposes to help the reader in understanding the principles of the proposed methods and systems. Furthermore, all statements herein providing principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass equivalents thereof.
[0093] The present disclosure also comprises the following aspects, which are not claims. [0094] 1. A control circuit for controlling a power converter; wherein the control circuit is configured to [0095] operate the power converter in a pulse frequency modulation, PFM, mode, using a set of activated PFM functional blocks, while a set of PWM functional blocks for operating the power converter in a pulse width modulation, PWM, mode is inactive; and [0096] enter a handover state, within which [0097] the power converter is operated in the PFM mode; and [0098] one or more PWM functional blocks of the set of PWM functional blocks are activated. [0099] 2. The control circuit of aspect 1, wherein the control circuit is configured to enter the handover state in preparation of a transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode. [0100] 3. The control circuit of aspect 1 or 2, wherein the one or more PWM functional blocks which are activated in the handover state are configured to [0101] determine a deviation of an output voltage of the power converter from a target voltage; and/or [0102] determine an adaptive peak current threshold which is used for generating a trigger for turning on or off a power switch of the power converter. [0103] 4. The control circuit of any one of aspects 1 to 3, wherein the one or more PWM functional blocks which are activated in the handover state are configured to compare an inductor current through an inductor of the power converter with a peak current threshold for generating a trigger for turning on or off a power switch of the power converter. [0104] 5. The control circuit of any one of aspects 1 to 4, wherein the control circuit is configured to maintain one or more PWM functional blocks of the set of PWM functional blocks deactivated within the handover state. [0105] 6. The control circuit of aspect 5, wherein the one or more PWM functional blocks which are maintained deactivated within the handover state comprise, [0106] one or more PWM functional blocks for generating a clock signal; [0107] one or more PWM functional blocks for generating a ramp signal; and/or [0108] one or more PWM functional blocks for detecting that the power converter may be put into a sleep condition. [0109] 7. The control circuit of any one of aspects 1 to 6, wherein the control circuit is configured to [0110] determine that a handover condition for entering the handover state is met; and [0111] enter the handover state, in reaction to determining that the handover condition is met. [0112] 8. The control circuit of aspect 7, wherein the handover condition is dependent on, [0113] a switching frequency at which the power converter is operated within the PFM mode; and/or [0114] a load current which is provided at an output of the power converter; and/or [0115] an input voltage and/or an output voltage of the power converter. [0116] 9. The control circuit of aspect 7 or 8, wherein the control circuit is configured to [0117] determine that the handover condition is not met anymore; and [0118] in reaction to determining that the handover condition is not met anymore [0119] deactivate the one or more PWM functional blocks which had been activated within the handover state; and [0120] operate the power converter in the PFM mode, using the set of activated PFM functional blocks, while the set of PWM functional blocks for operating the PWM mode is inactive. [0121] 10. The control circuit of aspect 2 or any one of aspects 3 to 9 when depending on aspect 2, wherein the control circuit is configured to [0122] compare an inductor current through an inductor of the power converter with a fixed current threshold when operating the power converter in the PFM mode to generate an OFF-trigger for turning off one or more switches of the power converter; [0123] compare the inductor current with an adaptive current threshold when operating the power converter in the PFM mode to generate an OFF-trigger for turning off the one or more switches of the power converter; and [0124] perform the transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode in dependence of the fixed current threshold and the adaptive current threshold. [0125] 11. The control circuit of aspect 10, wherein the control circuit is configured to [0126] compare the adaptive current

threshold with the fixed current threshold; and [0127] perform the transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode, if the adaptive current threshold reaches or exceeds the fixed current threshold. [0128] 12. The control circuit of aspect 10 or 11, wherein the control circuit is configured to determine the adaptive current threshold within the handover state using the one or more activated PWM functional blocks. [0129] 13. The control circuit of any one of aspects 10 to 12, wherein the control circuit is configured to determine the adaptive current threshold based on a deviation of an output voltage of the power converter from a target voltage. [0130] 14. The control circuit of aspect 2 or any one of aspects 3 to 13 when depending on aspect 2, wherein the control circuit is configured to, in the context of the transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode, [0131] activate the one or more PWM functional blocks from the set of PWM functional blocks that had not been activated in the handover state; and/or [0132] deactivate the set of activated PFM functional blocks. [0133] 15. A power converter system comprising, [0134] a power converter; and [0135] the control circuit according to any one of aspects 1 to 14 for controlling the power converter. [0136] 16. A method for controlling a power converter; wherein the method comprises, [0137] operating the power converter in a pulse frequency modulation, PFM, mode, using a set of activated PFM functional blocks, while a set of PWM functional blocks for operating the power converter in a pulse width modulation, PWM, mode is inactive; and [0138] entering a handover state, within which [0139] the power converter is operated in the PFM mode; and [0140] one or more PWM functional blocks of the set of PWM functional blocks are activated. [0141] 17. The method of claim **16**, wherein the handover state is entered in preparation of a transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode.

Claims

1. A control circuit for controlling a power converter; wherein the control circuit is configured to operate the power converter in a pulse frequency modulation, PFM, mode, using a set of activated PFM functional blocks, while a set of PWM functional blocks for operating the power converter in a pulse width modulation, PWM, mode is inactive; and enter a handover state, within which the power converter is operated in the PFM mode; and one or more PWM functional blocks of the set of PWM functional blocks are activated.
2. The control circuit of claim 1, wherein the control circuit is configured to enter the handover state in preparation of a transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode.
3. The control circuit of claim 1, wherein the one or more PWM functional blocks which are activated in the handover state are configured to determine a deviation of an output voltage of the power converter from a target voltage; and/or determine an adaptive peak current threshold which is used for generating a trigger for turning on or off a power switch of the power converter.
4. The control circuit of claim 1, wherein the one or more PWM functional blocks which are activated in the handover state are configured to compare an inductor current through an inductor of the power converter with a peak current threshold for generating a trigger for turning on or off a power switch of the power converter.
5. The control circuit of claim 1, wherein the control circuit is configured to maintain one or more PWM functional blocks of the set of PWM functional blocks deactivated within the handover state.
6. The control circuit of claim 5, wherein the one or more PWM functional blocks which are maintained deactivated within the handover state comprise, one or more PWM functional blocks for generating a clock signal; one or more PWM functional blocks for generating a ramp signal; and/or one or more PWM functional blocks for detecting that the power converter may be put into a sleep condition.

7. The control circuit of claim 1, wherein the control circuit is configured to determine that a handover condition for entering the handover state is met; and enter the handover state, in reaction to determining that the handover condition is met.
8. The control circuit of claim 7, wherein the handover condition is dependent on, a switching frequency at which the power converter is operated within the PFM mode; and/or a load current which is provided at an output of the power converter; and/or an input voltage and/or an output voltage of the power converter.
9. The control circuit of claim 7, wherein the control circuit is configured to determine that the handover condition is not met anymore; and in reaction to determining that the handover condition is not met anymore deactivate the one or more PWM functional blocks which had been activated within the handover state; and operate the power converter in the PFM mode, using the set of activated PFM functional blocks, while the set of PWM functional blocks for operating the PWM mode is inactive.
10. The control circuit of claim 1, wherein the control circuit is configured to compare an inductor current through an inductor of the power converter with a fixed current threshold when operating the power converter in the PFM mode to generate an OFF-trigger for turning off one or more switches of the power converter; compare the inductor current with an adaptive current threshold when operating the power converter in the PFM mode to generate an OFF-trigger for turning off the one or more switches of the power converter; and perform the transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode in dependence of the fixed current threshold and the adaptive current threshold.
11. The control circuit of claim 10, wherein the control circuit is configured to compare the adaptive current threshold with the fixed current threshold; and perform the transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode, if the adaptive current threshold reaches or exceeds the fixed current threshold.
12. The control circuit of claim 10, wherein the control circuit is configured to determine the adaptive current threshold within the handover state using the one or more activated PWM functional blocks.
13. The control circuit of claim 10, wherein the control circuit is configured to determine the adaptive current threshold based on a deviation of an output voltage of the power converter from a target voltage.
14. The control circuit of claim 1, wherein the control circuit is configured to, in the context of the transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode, activate the one or more PWM functional blocks from the set of PWM functional blocks that had not been activated in the handover state; and/or deactivate the set of activated PFM functional blocks.
15. A power converter system comprising, a power converter; and the control circuit according to claim 1 for controlling the power converter.
16. A method for controlling a power converter; wherein the method comprises, operating the power converter in a pulse frequency modulation, PFM, mode, using a set of activated PFM functional blocks, while a set of PWM functional blocks for operating the power converter in a pulse width modulation, PWM, mode is inactive; and entering a handover state, within which the power converter is operated in the PFM mode; and one or more PWM functional blocks of the set of PWM functional blocks are activated.
17. The method of claim 16, wherein the handover state is entered in preparation of a transition from operating the power converter in the PFM mode to operating the power converter in the PWM mode.