US 20070030714A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2007/0030714 A1

Bucur et al. (43) Pub. Date: Feb. 8, 2007

(54) ENABLING CIRCUIT FOR AVOIDING NEGATIVE VOLTAGE TRANSIENTS

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(21) Appl. No.: **11/535,173**

(22) Filed: **Sep. 26, 2006**

Related U.S. Application Data

(63) Continuation of application No. 11/142,505, filed on Jun. 1, 2005, now Pat. No. 7,112,943, which is a continuation of application No. 10/738,058, filed on Dec. 17, 2003, now Pat. No. 6,906,497, which is a continuation of application No. 10/176,141, filed on Jun. 20, 2002, now Pat. No. 6,756,769.

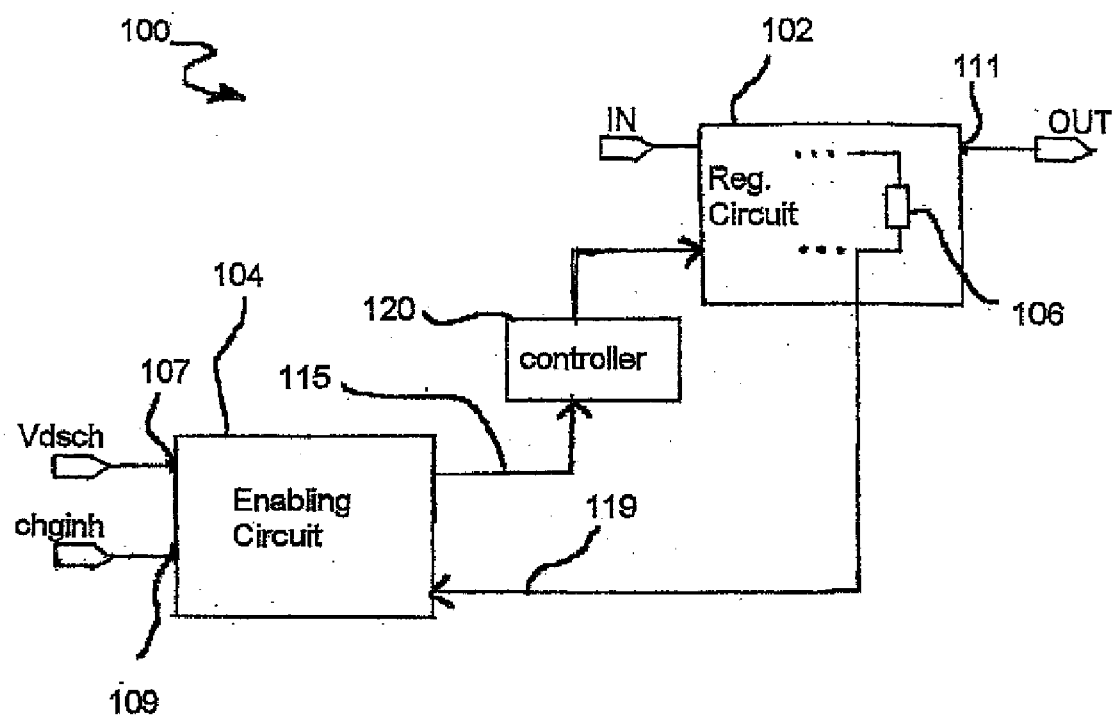
Publication Classification

(51) **Int. Cl.**
G05F 3/06 (2006.01)

(52) **U.S. Cl.** **363/75**

(57) ABSTRACT

An enabling circuit for enabling a DC-DC converter having a capacitor coupled to an output terminal of the DC-DC converter to be controlled by a control signal. The enabling circuit may include a comparison circuit configured to compare a feedback signal representative of a charge on the capacitor with a signal representative of a reference charge and to provide an output to in response to the comparison to enable the DC-DC converter to be controlled by the control signal if the charge on the capacitor is less than the reference charge. The enabling circuit may also include a discharge path configured to discharge the charge on the capacitor if the charge is greater than the reference charge. A related system and method are also provided.



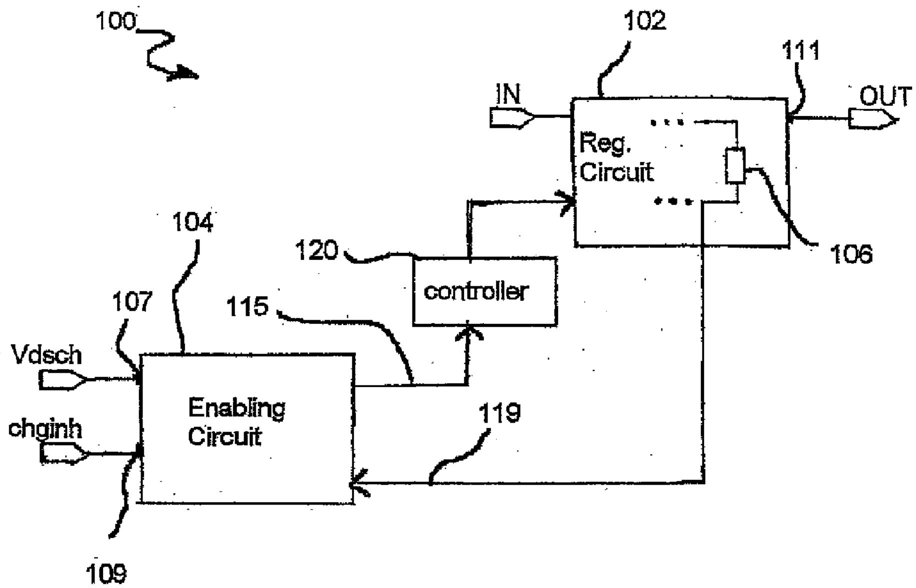

100
102
111
IN
OUT
Reg.
Circuit
106
104
120
controller
107
115
Vdsch
Enabling
Circuit
chginh
119
109

FIG. 1

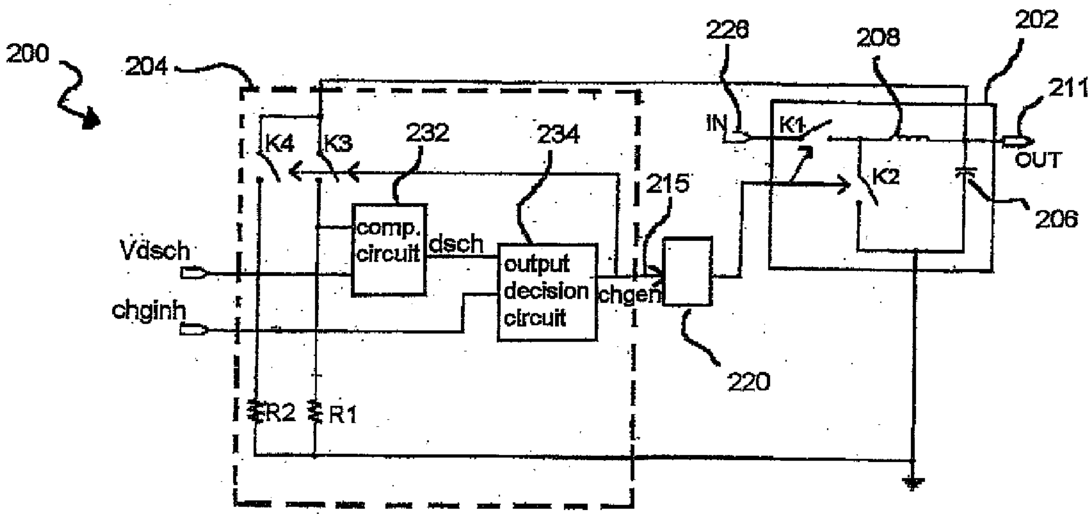

200
204
228
208
202
211
IN
K1
OUT
K4
K3
232
234
215
K2
206
Vdsch
comp.
circuit
dsch
output
decision
circuit
chgen
chginh
220
R2
R1

FIG. 2

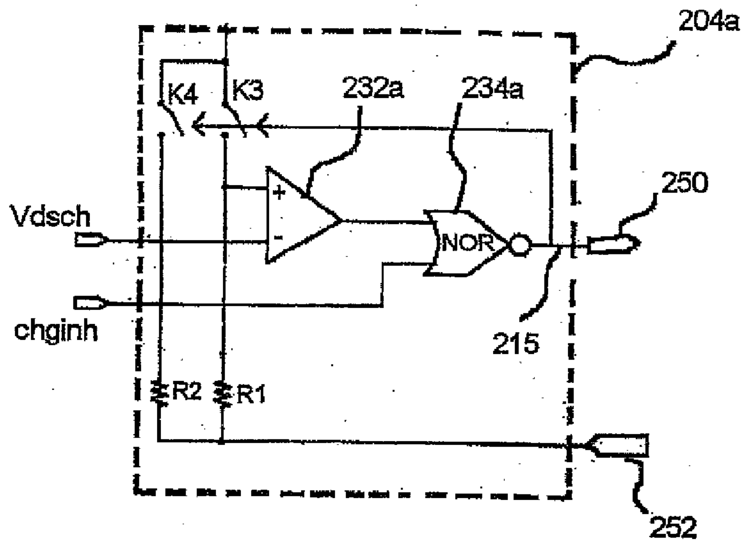

204a
K4
K3
232a
234a
250
Vdsch
NOR
chginh
215
R2
R1
252

FIG. 2A

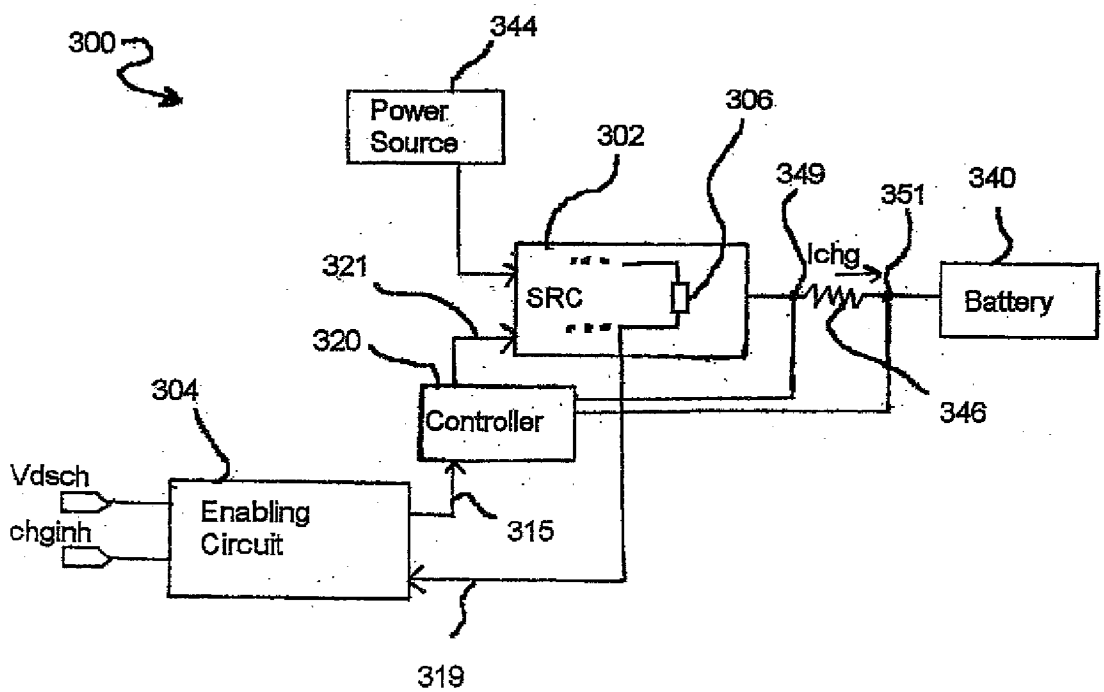

300
344
Power Source
306
302
349
351
340
Ichg
321
SRC
Battery
320
304
Controller
346
Vdsch
Enabling Circuit
chginh
315
319

FIG. 3

ENABLING CIRCUIT FOR AVOIDING NEGATIVE VOLTAGE TRANSIENTS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of prior application Ser. No. 11/142,505 filed Jun. 1, 2005, now U.S. Pat. No. 7,112,943, which itself is a continuation of prior application Ser. No. 10/738,058 filed Dec. 17, 2003, now U.S. Pat. No. 6,906,497, which itself is a continuation of prior application Ser. No. 10/176,141, filed Jun. 20, 2002, now U.S. Pat. No. 6,756,769, the teachings of which are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] This invention relates to an enabling circuit for avoiding negative voltage transients from an associated regulating circuit, and more particularly to such an enabling circuit for enabling a synchronous rectifier converter to switch from a first state to second state if the charge on an energy storage element of the synchronous rectifier converter is less than a reference charge.

BACKGROUND OF THE INVENTION

[0003] A variety of circuits have energy storage element such as capacitors, inductors, and transformers that transfer energy from an input to an output of such circuits. If such energy storage elements are not properly discharged in some instances, unwanted power disturbances, e.g., negative voltage transients, may occur in the output signal causing damage to nearby sensitive components.

[0004] For instance, such a regulating circuit may be a DC-DC converter. DC-DC converters generally accept a DC input at one voltage level and convert it to a DC output at a higher or lower voltage level. Such DC-DC converters may be used in a wide variety of electronic devices in conjunction with a variety of systems. One such system may be used to provide a battery charging function for portable electronic devices such as laptop computers, cell phones, pagers, personal digital assistants, and the like.

[0005] One type of DC-DC converter is a synchronous rectifier converter (SRC). An SRC does not use any Schottky diodes, but rather uses transistors referred to as "synchronous rectifiers." Such transistors may be a variety of transistors such as MOS or MOSFET transistors. An SRC may also have a variety of internal components that typically include an energy storage element, e.g., a capacitor, inductor, or transformer, with one or more transistors controlled by various control techniques, e.g., pulse width modulation where the switch frequency is constant and the duty cycle varies with the load.

[0006] When an SRC is used in conjunction with a battery power management system, the SRC may accept an input voltage from a number of different power sources and convert it to an appropriate output voltage to, among other things, provide an appropriate charging current to an associated rechargeable battery. In such a battery power management system, there is typically an associated controller used to control the battery charging process. Such controller may be an integrated circuit (IC) having a plurality of input terminals or pins, some of which are connected to the output of the SRC. For instance, two such terminals may be coupled to either side of a sense resistor. The sense resistor may be in series with the output of the SRC such that it provides a signal representative of the charging current provided at the output of the SRC.

[0007] If a soft start occurs when the energy storage element, e.g., a capacitor, of the SRC is charged at a significant value, e.g., over several volts, negative voltage transients may appear on either terminal of the sense resistor potentially causing catastrophic failure of the associated controller IC. Accordingly, there is a need for an enabling circuit and method that overcomes the above deficiencies in the prior art and is capable of avoiding negative voltage transients from an associated regulating circuit by enabling the regulating circuit only when the charge on the energy storage element is below a reference charge.

BRIEF SUMMARY OF THE INVENTION

[0008] According to one aspect of the invention, there is provided an enabling circuit for enabling a DC-DC converter having a capacitor coupled to an output terminal of the DC-DC converter to be controlled by a control signal. The enabling circuit may include a comparison circuit configured to compare a feedback signal representative of a charge on the capacitor with a signal representative of a reference charge and to provide an output to in response to the comparison to enable the DC-DC converter to be controlled by the control signal if the charge on the capacitor is less than the reference charge. The enabling circuit may also include a discharge path configured to discharge the charge on the capacitor if the charge is greater than the reference charge.

[0009] According to another aspect of the invention, there is provided a system. The system may include a DC-DC converter configured to accept an input power level from a power source and provide a regulated output power level to a load. The DC-DC converter may have a capacitor coupled to an output terminal of the DC-DC converter. The system may further include an enabling circuit for enabling the DC-DC converter to be controlled by a control signal. The enabling circuit may include a comparison circuit configured to compare a feedback signal representative of a charge on the capacitor with a signal representative of a reference charge and to provide an output to in response to the comparison to enable the DC-DC converter to be controlled by the control signal if the charge on the capacitor is less than the reference charge. The enabling circuit may also include a discharge path configured to discharge the charge on the capacitor if the charge is greater than the reference charge.

[0010] According to yet another aspect of the invention there is provided a method. The method may include monitoring a charge on a capacitor of a DC-DC converter coupled to an output terminal of said DC-DC converter; preventing the DC-DC converter from being controlled by a control signal if the charge is greater than the reference charge; and enabling the DC-DC converter to be controlled by the control signal if the charge is less than the reference charge.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] For a better understanding of the present invention, together with other objects, features and advantages, reference should be made to the following detailed description which should be read in conjunction with the following figures wherein like numerals represent like parts:

[0012] FIG. **1** is a block diagram of a system including an enabling circuit consistent with the present invention for enabling an associated regulating circuit to switch from a first state to a second state;

[0013] FIG. **2** is a block diagram of an exemplary enabling circuit consistent with the invention for enabling an associated synchronous rectifier converter to switch from one state to another state;

[0014] FIG. **2**A is a circuit diagram illustrating an exemplary embodiment of the enabling circuit of FIG. **2**; and

[0015] FIG. **3** is a block diagram of a battery management system utilizing the enabling circuit of FIG. **2**.

DETAILED DESCRIPTION

[0016] Turning to FIG. **1**, an exemplary system **100** including an enabling circuit **104** and an associated regulating circuit **102** is illustrated. The regulating circuit **102** may be any variety of circuits, e.g., a synchronous rectifier converter, containing an energy storage element **106**, e.g., a capacitor. In general, the enabling circuit **104** monitors the charge on the energy storage element **106** and enables the regulating circuit **102** to switch from a first state to a second state when the charge on the energy storage element is below a reference charge. The first state may be any variety of states such as a power off state, and the second state may also be any variety of states such as an operating state where the regulating circuit **102** is controlled by a particular control technique. The reference charge should be chosen based on the particular system and sensitivity of associated components. In one embodiment, the reference charge may be 3.0 volts.

[0017] The enabling circuit **104** has one input terminal **107** configured to accept a signal, Vdsch, representative of an acceptable reference charge level for the energy storage element **106**. The enabling circuit **104** may have another input terminal **109** configured to accept a logic control signal chginh. Such logic control signal, chginh, has a predetermined state, e.g., low state, when at least one non energy storage element condition related to operation of the regulating circuit **102** is satisfied. Such a condition or conditions may be any variety of other conditions known to those skilled in the art unrelated to the charge on the energy storage element **106**. For instance, one condition may be the proper coupling of an input power source at a proper power level to the input of the regulating circuit **102**.

[0018] The enabling circuit **104** accepts a feedback signal from the regulating circuit **102** along path **119**. Such feedback signal is representative of the charge on the energy storage element **106**. The enabling circuit compares the charge on energy storage element **106** with a reference charge and may output an enabling signal if the charge level is less than the reference charge level. The enabling circuit **104** may also include various discharging means as further described in reference to FIG. **2** in order to discharge the energy storage element **106** below the reference charge level should the charge be greater than the reference charge level.

[0019] In one embodiment, once the charge on the energy storage element **106** is below the reference charge, the enabling circuit **104** sends an enabling signal along path **115** to the controller **120**. The controller **120** is responsive to the enabling signal to then enable the regulating circuit to switch from a first state, e.g., a non-operating state or a predetermined suitable operating state, to a second state, e.g., another operating state. As such, an enabling circuit **104** consistent with the invention may advantageously delay operation of the regulating circuit **102** in the second state while maintaining operation of the regulating circuit **102** in the first state until the energy storage element **106** is discharged below a reference charge.

[0020] In another embodiment, the enabling circuit **104** may not send an enabling signal to the controller **120** until both the energy storage element **106** is discharged below the reference charge level and a logic control signal, e.g., signal chginh, input to the enabling circuit is at a predetermined state. Such predetermined state is representative of at least one satisfactory non energy storage element condition. Such predetermined state may also be representative of a satisfactory condition for all other non energy storage element conditions. In this case, an enabling circuit **104** consistent with the invention delays switching the regulating circuit **102** to operation in the second state while maintaining operation of the regulating circuit **102** in the first state, e.g., a non-operating state or a predetermined suitable operating state, until the energy storage element **106** is discharged below a predetermined charge level and a signal representing at least one satisfactory non energy storage element condition related to operation of the regulating circuit is satisfied.

[0021] Turning to FIG. **2**, one exemplary system **200** having an enabling circuit **204** consistent with the invention and a synchronous rectifier converter (SRC) **202** is illustrated. The SRC accepts an input voltage signal at input terminal **226** and provides an output voltage signal at output terminal **211**. The SRC may include an inductor **208**, a capacitor **206** and switches K**1**, K**2**. Switches K**1**, K**2** may be any type of transistors and for simplicity are drawn to represent MOS type transistors. Such switches K**1**, K**2** may be controlled by a variety of control techniques such as pulse width modulation (PWM) where the switch frequency is constant and the duty cycle varies with load, pulse-frequency modulation, or current-limited pulse-frequency modulation as those control techniques are known to those skilled in the art.

[0022] The enabling circuit **204** may include a comparator circuit **232**, an output decision circuit **234**, and discharge path including resistors R**1**, R**2** and switches K**3**, K**4**. The comparator circuit **232** may be any variety of circuits for comparing the charge on the capacitor **206** to a predetermined reference value charge represented by control signal Vdsch input to the comparator circuit. The comparator circuit **232** is configured to provide an output signal to maintain the SRC **202** in the first state, e.g., a non-operating state or a predetermined suitable operating state, if the charge on the capacitor **206** is higher than the reference charge. The comparator circuit **232** is also configured to provide output signal to switch the SRC **202** from the first state to a second state, e.g., another operating state where switches K**1**, K**2** are under control of the controller **220**, if the charge on the capacitor **206** is less than the reference charge.

[0023] The output decision circuit **234** may be any variety of circuits for performing a desired logic function. The output decision circuit **234** accepts the output signal dsch from the comparator circuit **232** and may further accept a logic signal chginh from a separate source. The output decision circuit **234** may be configured to output an enabling signal on path **215** to the controller **220** if signal dsch indicates the charge on the capacitor **206** is less than a reference charge level. The output decision circuit **234** may alternately require signal dsch to indicate the charge on the capacitor **206** is less than a reference charge level, and require signal chginh to be in a predetermined state, e.g., low state, when at least one non energy storage element condition is satisfied. The output decision circuit **234** is not a necessary part of the enabling circuit **204** if the logic signal chginh is not input to the enabling circuit. In this case, the comparator circuit **232** would provide the enabling signal if the charge on the capacitor **206** is less than the reference charge.

[0024] The enabling circuit **204** may also include a discharge path including resistors R**1**, R**2**, and switches K**3**, K**4** to discharge the capacitor **206** below a reference level. Switches K**3**, K**4** may be any type of transistors and for simplicity are drawn to represent MOS type transistors. Detailed operation of an enabling circuit and the discharge path is made later with reference to the exemplary enabling circuit of FIG. **2**A.

[0025] Turning to FIG. **2**A, a circuit diagram of one exemplary enabling circuit **204***a* is illustrated. Those skilled in the art will recognize a variety of circuit configurations which may be utilized in an enabling circuit consistent with the present invention. In the exemplary embodiment of FIG. **2**A, the comparator circuit **232** of FIG. **2** includes a comparator **232***a* having its positive input terminal accepting the input signal representative of the charge on the capacitor **206** and its negative input terminal accepting the other input control signal, Vdsch, representative of a reference value charge.

[0026] The output decision circuit **234** includes a NOR gate **234***a*. The NOR gate **234***a* accepts the output from the comparator **232***a* and the control signal chginh. The output of the NOR gate **234***a* is HIGH only if all inputs are LOW. Otherwise, the output of the NOR gate **234***a* is LOW. In this embodiment, the enabling signal sent by the enabling circuit **204** to the controller **220** to enable the regulating circuit **202** to switch from the first state, e.g. switches K**1**, K**2** open, to the second state state, e.g., switches K**1**, K**2** under control of controller **220**, is sent when the output of the NOR gate is HIGH.

[0027] Operation of the exemplary enabling circuit **204***a* in conjunction with the system **200** is described further herein with reference to the Truth Table of Table 1. Table 1 details the status of the various control signals and switches relative to each other with the output decision circuit **234** functioning as the NOR gate **234***a* of FIG. **2**A. The status of control signal chginh input to the enabling circuit **204**, control signal dsch output from comparator **232***a,* control signal chgen output from the NOR gate **234***a,* switches K**1**, K**2** of the SRC **202**, and switches K**3**, K**4** of the enabling circuit **204** are all detailed in Table 1.

TABLE 1

chginh	H	H	L	L
dsch	H	L	H	L
chgen	L	L	L	H
K1	OFF	OFF	OFF	PWM
K2	OFF	OFF	OFF	PWM
K3	ON	ON	ON	OFF
K4	ON	ON	ON	OFF

[0028] As illustrated and described more fully herein, the exemplary enabling circuit **204***a* advantageously does not enable switches K**1**, K**2** of the SRC **204** to be controlled by the proper control technique, e.g., PWM control, and maintains switches K**1**, K**2** in an OFF position, until the capacitor **206** of the SRC **202** is discharged below a reference charge (control signal dsch is L), and at least one other non capacitor charge related condition for operation of the regulating circuit (control signal chginh is L) is satisfied. As such, negative voltage transients that may otherwise occur at the output terminal **211** of the SRC **202** are avoided.

[0029] As illustrated in the first substantive column of Table 1, if the charge level on capacitor **206** is greater than a reference charge level as represented by control signal Vdsch input to the comparator **232***a,* then the control signal dsch output from the comparator **232***a* is HIGH. The output control signal dsch from the comparator **232***a* is then input to the NOR gate **234***a*.

[0030] The other input to the NOR gate **234***a* may be the control signal chginh from a separate source. Such control signal chginh is representative of at least one non capacitor related condition pertinent to operation of the SRC **202**. In this embodiment, if this chginh signal is LOW, at least one and perhaps all other non capacitor related conditions pertinent to operation of the SRC **202** are satisfactory. If this chginh signal is HIGH, such condition or conditions are unsatisfactory. Accordingly, if the output control signal dsch from the comparator **232***a* is HIGH and the chginh signal is also HIGH, the output signal from the NOR gate **234***a* is LOW. Thus, switches K**1** and K**2** remain OFF or open and the operation of the SRC **202** is delayed. As such, if the SRC is operating to provide a charging current to an associated rechargeable battery, such charging current would not be provided in this instance, nor would current flow from the capacitor **206** through the inductor **208** be possible in this instance.

[0031] Turning to the second substantive column of Table 1, if the capacitor **206** is discharged below the reference charge represented by control signal Vdsch, the output control signal dsch from the comparator **232***a* goes LOW indicating the charge level on the capacitor **206** is acceptable. However, if another non capacitor charge related condition is unsatisfactory, the control signal chginh remains HIGH. As such, the output of the NOR gate **234***a* remains LOW and the operation of the SRC **202** is still delayed.

[0032] Turning to the third substantive column of Table 1, if the control signal chginh is LOW representing a satisfactory starting condition for at least one non-charge related condition, but the output control signal dsch from the comparator **232***a* is HIGH, then the output signal chgen from the NOR gate **234***a* remains LOW. As such, the operation of the SRC **202** is still delayed.

[**0033**] As illustrated in the fourth substantive column of Table 1, it is not until the capacitor **206** is discharged below the reference charge level (control signal dsch output from the comparator **232***a* is LOW), and at least one if not all other non-charge related conditions for operation of the regulating circuit (control signal chginh is LOW) are satisfied, that the control signal chgen output of the NOR gate **234***a* is HIGH. Once the control signal chgen is HIGH, switches K**3** and K**4** of the enabling circuit **204** open or are in an OFF position. The HIGH control signal chgen enables the controller **220** to drive the SRC **202**. Hence, switches K**1**, K**2** are controlled by an appropriate control technique, e.g., PWM.

[**0034**] If the enabling signal is not present in this embodiment, switches K**3**, K**4** are closed or in an ON position. A discharge path for the capacitor **206** is then created through the switches K**3**, K**4**. Switch K**3** is further coupled in series to resistor R**1**, while switch K**4** is further coupled in series to resistor R**2**. Resistor R**1** has a resistive value that is higher than the resistive value for resistor R**2**. As such, when switches K**3**, K**4** are closed because no enabling signal from the NOR gate **234***a* is present, a discharge path is created and resistor R**2** serves to discharge the capacitor **206**.

[**0035**] Turning to FIG. **3**, an exemplary battery charging system **300** generally including a power source **344**, an SRC **302**, an enabling circuit **304** consistent with the invention, a rechargeable battery **340**, and a battery charging controller **320** is illustrated. Such a battery charging system **300** may be used in a variety of portable electronic devices such as laptop computers, cell phones, pagers, personal digital assistants, and the like to provide and control power flow to a rechargeable battery **340**, e.g., a lithium, nickel-cadmium, or nickel-metal hydride battery.

[**0036**] A sensor such as sense resistor **346** may be used in order to provide a sensed signal to the controller **320** indicative of the charging current Ichg to the battery. Such a controller **320** is typically an integrated circuit (IC) and may be sensitive to negative voltage transients that may otherwise occur at either terminal **349**, **351** if the energy storage element **306** is not properly discharged below a reference charge value. Such negative voltage transients may appear on either terminal **349**, **351** due to oscillation induced by an inductor and capacitor group of the SRC **302**.

[**0037**] Once a power source **344** is properly coupled to the system **300**, it provides an input DC voltage signal to the SRC **302**. The power source **344** may be an AC/DC adapter configured to receive conventional AC voltage from a power outlet and convert it to an applicable DC voltage, or a DC/DC adapter such as a "cigarette lighter" type adapter configured to plug into that type of socket, or other types of power sources.

[**0038**] Advantageously, the SRC **302** accepts power input from the power source **344** and converts it to a proper output voltage and current level for providing a charging current Ichg to the battery **340** only if the controller **320** receives an enabling signal from the enabling circuit **304** along path **315**. Otherwise, the controller **320** delays providing a charging current Ichg to the battery **340**, while keeping the SRC **302** in a predetermined suitable state. This predetermined suitable state may be any variety of states as determined by the position of various switches in the SRC **302**. In the previous embodiment of FIG. **2**, switches K**1**, K**2** of SRC **202** were chosen to be in an open state. The SRC **302** is controlled by the controller **320** by any variety of control techniques, e.g., PWM, known by those skilled in the art.

[**0039**] Advantageously therefore, the enabling circuit **304** delays providing of the charging current Ichg to the battery **340** until the energy storage element **306** is discharged below a reference charge. The enabling circuit **304** may also further delay the charging current Ichg to the battery **340** until another control signal, e.g., signal chginh, from another source indicates that at least one non-charge related condition pertinent to operation of the SRC **302** is satisfactory.

[**0040**] The embodiments that have been described herein, however, are but some of the several which utilize this invention and are set forth here by way of illustration but not of limitation. It is obvious that many other embodiments, which will be readily apparent to those skilled in the art, may be made without departing materially from the spirit and scope of the invention.

What is claimed is:

1. An enabling circuit for enabling a DC-DC converter having a capacitor coupled to an output terminal of said DC-DC converter to be controlled by a control signal, said enabling circuit comprising:

a comparison circuit configured to compare a feedback signal representative of a charge on said capacitor with a signal representative of a reference charge and to provide an output in response to said comparison to prevent said DC-DC converter from being controlled by said control signal if said charge on said capacitor is greater than said reference charge.

2. The enabling circuit of claim 1, wherein said comparison circuit comprises a discharge path configured to discharge said charge on said capacitor if said charge is greater than said reference charge.

3. The enabling circuit of claim 2, wherein said discharge path comprises at least one switch, said at least one switch configured to close to create said discharge path from said capacitor if said charge on said capacitor is greater than said reference charge.

4. The enabling circuit of claim 3, further comprising an output decision circuit configured to receive at least said output from said comparison circuit and provide an enabling signal to enable said DC-DC converter to switch from a first state wherein said DC-DC converter is not controlled by said control signal to a second state wherein said DC-DC converter is controlled by said control signal if said charge on said capacitor is less than said reference charge.

5. The enabling circuit of claim 4, wherein said output decision circuit is further configured to receive a condition signal, and wherein said output decision circuit provides said enabling signal in response to said condition signal.

6. The enabling circuit of claim 4, wherein said comparison circuit comprises a comparator.

7. The enabling circuit of claim 1 wherein said comparison circuit is configured to enable said DC-DC converter to be controlled by said control signal if said charge on said capacitor is less than said reference charge.

8. A system comprising:

a DC-DC converter configured to accept an input power level from a power source and provide a regulated output power level to a load, said DC-DC converter having a capacitor coupled to an output terminal of said DC-DC converter; and

an enabling circuit for enabling said DC-DC converter to be controlled by a control signal, said enabling circuit comprising:

a comparison circuit configured to compare a feedback signal representative of a charge on said capacitor with a signal representative of a reference charge and to provide an output in response to said comparison to prevent said DC-DC converter from being controlled by said control signal if said charge on said capacitor is greater than said reference charge.

9. The system of claim 8, wherein said comparison circuit comprises a discharge path configured to discharge said charge on said capacitor if said charge is greater than said reference charge.

10. The system of claim 9, wherein said discharge path comprises at least one switch, said at least one switch configured to close to create said discharge path from said capacitor if said charge on said capacitor is greater than said reference charge.

11. The system of claim 9, further comprising an output decision circuit configured to receive at least said output from said comparison circuit and provide an enabling signal to enable said DC-DC converter to switch from a first state wherein said DC-DC converter is not controlled by said control signal to a second state wherein said DC-DC converter is controlled by said control signal if said charge on said capacitor is less than said reference charge.

12. The enabling circuit of claim 11, wherein said output decision circuit is further configured to receive a condition signal, and wherein said output decision circuit provides said enabling signal in response to said condition signal.

13. The system of claim 8, wherein said comparison circuit comprises a comparator.

14. The system of claim 8 wherein said comparison circuit is configured to enable said DC-DC converter to be controlled by said control signal if said charge on said capacitor is less than said reference charge.

15. A method comprising:

monitoring a charge on a capacitor of a DC-DC converter coupled to an output terminal of said DC-DC converter;

preventing charging of said capacitor if said charge of said capacitor is greater than a reference charge; and

enabling said DC-DC converter to be controlled by a control signal if said charge of said capacitor is less than said reference charge.

16. The method of claim 15, further comprising discharging said capacitor if said charge is greater than said reference charge.

17. The method of claim 16, wherein said discharge operation further comprises closing a switch to create a discharge path from said capacitor to ground.

18. The method of claim 15 wherein said enabling step occurs if at least one non capacitor condition is satisfied.

* * * * *