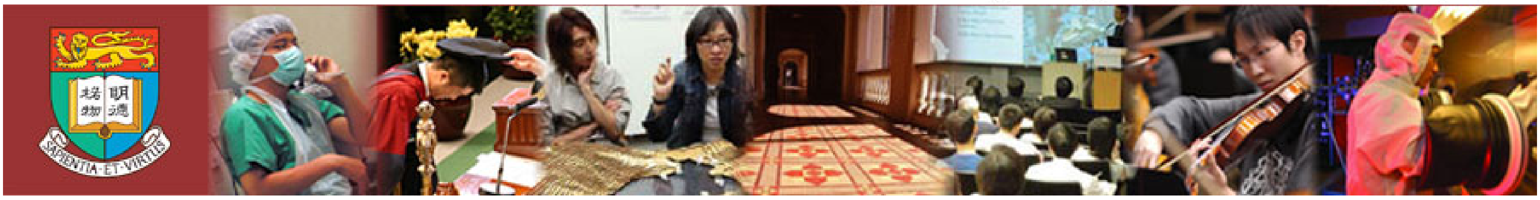

Title	Pre-energized compact auxiliary circuit to buffer loads from fast transients with the goal of managing load-informed power
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Pre-Energized Compact Auxiliary Circuit to Buffer Loads from Fast Transients with the Goal of Managing Load-Informed Power

Zhenyu Shan
Department of Electronic and Information Engineering
Hong Kong Polytechnic University
Hong Kong
zhenyu.shan@connect.polyu.hk

Philip T. Krein
Department of Electrical and Computer Engineering
University of Illinois at Urbana-Champaign
Urbana, Illinois, USA
krein@illinois.edu

Chi K. Tse
Department of Electronic and Information Engineering
Hong Kong Polytechnic University
Hong Kong
encktse@polyu.edu.hk

Siew-Chong Tan
Department of Electrical and Electronic Engineering
University of Hong Kong
Hong Kong
sctan@eee.hku.hk

***Abstract*—A pre-energized auxiliary circuit can be constructed to buffer fast load transients using advance information from an intelligent load. Such information should include the exact times of load transients and their magnitudes. This paper proposes a compact auxiliary circuit that generates a current half the magnitude of the transient. The proposed circuit builds on earlier work addressing load-informed power and operates to pre-energize the power supply. The goal is to integrate it with an intelligent load.**

I. Introduction

The usual consideration for dynamic performance of a power supply assumes that load changes are unknown, although the range of load changes is normally specified. A negative feedback loop is employed to respond to output current changes. In a switching power converter, the inductor current is regulated by the feedback loop with limited slew rate. A delay is incurred when using a switching power converter to reach a new operating point. This may be caused by changing an inductor current. During the delay period, the output energy storage element (capacitor) will need to address the instantaneous energy imbalance, which will in turn incur overshoots or undershoots of v_o from the reference value. When the load varies at a high slew rate, a larger capacitor and complicated control algorithm [1], [2] are needed. Either the power supply size or complexity will increase.

Auxiliary circuit-based methods constructing an extra energy transfer path to the load to handle fast transients have been proposed [3]–[13]. One challenge is accurate transient detection. Another is balancing efficiency and capability in suppressing voltage deviations. Circuits based on simple active resistors can achieve fast transients but have lower efficiency [3]–[6]. Auxiliary circuits working in switching mode with inductors can improve efficiency but cannot generate an ideal negative transient [7]–[13].

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Methods for intelligent power management based on a load-informing power paradigm shift have been proposed. Shenoy and Krein showed that communication between the load and power supply is possible and will benefit power delivery performance, e.g., load transients dynamics [14]. Tang proposed a circuit using capacitors and load predictions to feed fast load transients [15]. To simplify the system and improve efficiency, a pre-energized auxiliary circuit was studied [16]. In this method, the combination of an actual load, e.g., microprocessor, and the auxiliary circuit will become an equivalent load without transient requirements (see Fig. 1). Then a general power supply with a traditional proportional-integral (PI) controller can deliver power for the load.

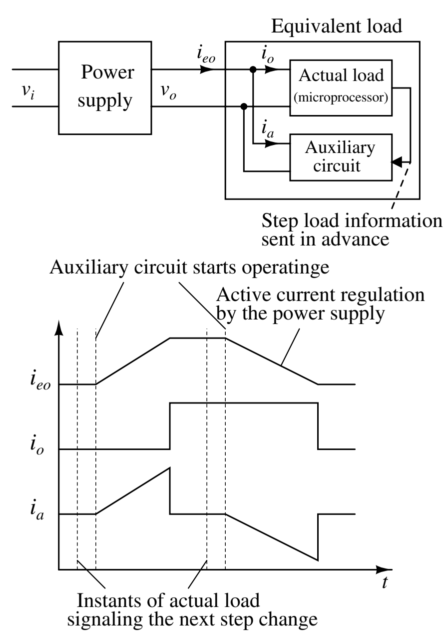

Fig. 1. Pre-energized auxiliary circuit working with load-informed power.

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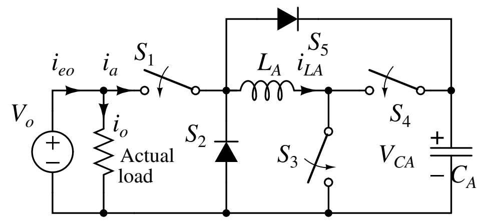

Fig. 2. Auxiliary circuit to provide the transient-size slow sloping current.

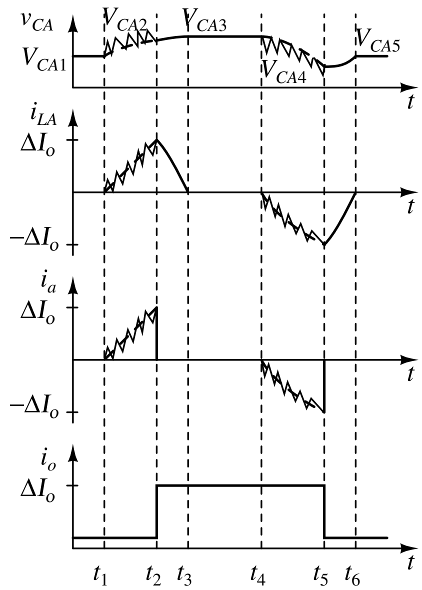

Fig. 3. The auxiliary circuit waveforms during four operating stages for ΔI_o stepping up at t_2 and down at t_5, respectively.

The pre-energized strategy can be optimized with an improved circuit. This paper discusses a compact auxiliary circuit using advance load information. Circuit size, power rating and energy loss are all reduced. The goal is to manage the load-informed power and integrate the power circuit with loads.

II. Compact Auxiliary Circuit for the Pre-energized Strategy

A. Review of Pre-energized Auxiliary Circuit

Prior to applying the transient in i_o (Fig. 1), the auxiliary circuit sinks or releases a slowly changing current which ramps from zero to the i_o transient level. When i_o transients occur, the auxiliary circuit cuts its output. This results in delivering a fast transient i_o and avoids a fast transient at i_{eo} [16]. This circuit is shown in Fig. 2. The operational waveform is shown in Fig. 3. To limit the size of reactive components, the auxiliary circuit may operate in switching mode during [t_1, t_2] and [t_4, t_5]. The mean current of i_a corresponding to the trajectory of Fig. 3 (shown by the dashed line) will be achieved by controlling the duty cycle.

The above implementation needs to generate a transient-size ramping current which is proportional to the energy storage and dissipation. From Fig. 3, it can be observed that the

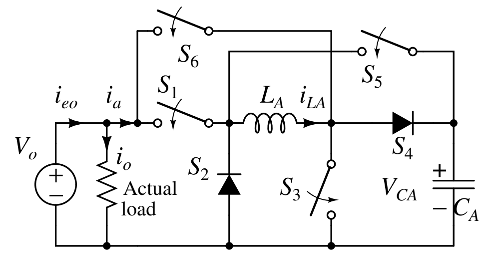

Fig. 4. Compact auxiliary circuit to provide the half transient-size sloping current and change the current direction at a transient time.

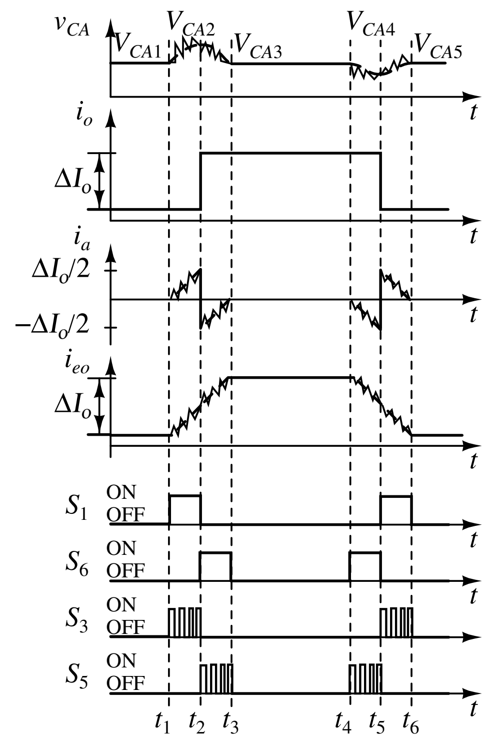

Fig. 5. The compact auxiliary circuit waveforms during four operational stages for ΔI_o stepping up at t_2 and down at t_5.

auxiliary circuit must receive the load prediction earlier than t_1 (or t_4); otherwise i_a cannot interact with i_o at t_2 (or t_5).

B. Pre-energized Compact Auxiliary Circuit

The topology and operational principles of the proposed compact auxiliary circuit are shown in Figs. 4 and 5, respectively. Prior to t_1, the auxiliary circuit should have received the prediction of the transient at t_2. It will begin sinking current at t_1 and continue gradually until t_2. The input current will reach half of the transient value ($\Delta I_o/2$) at t_2. A load step-up at t_2 interacts with the auxiliary circuit current, reversed from sinking to releasing. In [t_2, t_3], the auxiliary circuit reduced its output current in the slew rate as in [t_1, t_2]. The power supply is feeding transient-free ramping current, shown as i_{eo} in [t_1, t_3]. The ramping current slew rate is set at an acceptable value for the power supply. For step-down transients, the circuit operating order is reversed. The auxiliary circuit gradually releases current in $[t_4, t_5]$ and reverses current from output to input at t_5.

C. Two Operations

1) Sinking Currents ($[t_1, t_2]$ and $[t_4, t_5]$): In these two durations, S_1 is on and S_3 is the active switch to control i_{LA} which is equal to i_a. The turn-on duty cycle of S_3 will control the current ramping of i_{LA}. Assuming v_{ca} is always larger than V_o, the circuit operates in boost converter mode. The voltage is rising from V_{CA1} to V_{CA2} (or V_{CA4} to V_{CA5}) as the circuit is sinking current.

2) Releasing Currents ($[t_2, t_3]$ and $[t_5, t_6]$): During these two periods, S_6 is on and S_5 is the active switch to control i_{LA} which is equal to $-i_a$. The turn-on duty cycle of S_5 will control the current ramping of i_{LA}. Assuming v_{ca} is always larger than V_o, the circuit operates in buck converter mode. The voltage is dropping from V_{CA2} to V_{CA3} (or V_{CA3} to V_{CA4}) with the releasing current.

D. Capacitor Requirement

In $[t_4, t_5]$, the auxiliary circuit releases energy from C_A. The energy storage requirement depends on the transient size (ΔI_o), slew rate of mean i_a (k_{ad}), and the value of V_{CA3} and V_{CA4}, i.e.,

$$\frac{1}{2}C_A(V_{CA3}^2 - V_{CA4}^2) \geq \frac{V_o \Delta {I_o}^2}{8k_{ad}} + \frac{1}{8}L_A \Delta {I_o}^2 \qquad (1)$$

where energy loss is neglected. Hence C_A needs to satisfy

$$C_A \geq \frac{\dfrac{V_o \Delta {I_o}^2}{k_{ad}} + L_A \Delta {I_o}^2}{4(V_{CA3}^2 - V_{CA4}^2)}. \qquad (2)$$

III. Simulation

A. Simulation Model

The simulation model consists of a 12 V to 1.5 V dc-dc converter (parameters in Table I) and two auxiliary circuits. The schematic diagram is shown in Fig. 6. *Auxiliary circuit I* is constructed to operate as in Fig. 3. Suitable duty cycles control the slew rate of i_a limited by 80 A/ms. The switching ripple on i_a is limited by 2 A. *Auxiliary circuit II* is constructed to operate as in Fig. 5 with the same limits as *Auxiliary circuit I*.

TABLE I
PARAMETERS OF THE DC-DC SYNCHRONIZED BUCK CONVERTER (WHICH SERVES AS THE EXTERNAL POWER SUPPLY TO THE LOAD)

Parameters/Components	Values
Input voltage	12 V
Output voltage	1.5 V
Inductance	0.47 μH
Output capacitance	2 × 100 μF 2 × 330 μF
Maximum current	20 A
Switching frequency	300 kHz
Operation mode	Continuous mode
Control	Current mode control

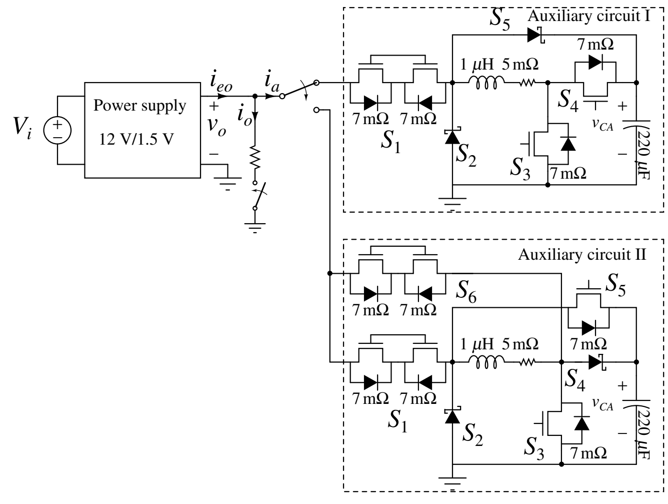

Fig. 6. Simulation model to compare the compact auxiliary circuit and the previous auxiliary circuit for the pre-energize scheme.

B. Simulation Results

Load transients of 0–20 A and 20–0 A are applied at 0.5 ms and 1.0 ms, respectively, to test system performance. The key waveforms of the two circuits are compared in Fig. 7. Voltage deviation mitigation is almost equal. The voltage did not exceed a 1.5 V±10 mV band (see Fig. 7(a)). It can be observed from Fig. 7(c) that *Auxiliary Circuit II* incurred less energy loss. The initial energy storage of the two circuits is identical (v_{CA} is 8.0 V); however at the end of the simulation, v_{CA} of *Auxiliary circuit I* and *Auxiliary circuit II* are 6.6 V and 7.4 V, respectively. Thus, a $\Delta I_o/2$ current (applied by *Auxiliary circuit II*) can reduce both energy loss and C_A size for the pre-energized scheme. To further reduce energy loss, two diodes (in Fig. 4) may be replaced by two synchronous MOSFETs.

IV. Conclusion

A compact auxiliary circuit to achieve a pre-energized scheme for fast transients in a computer power supply system has been discussed. The auxiliary power circuit uses the load-demand prediction for power management. Compared to previous auxiliary circuits, this one generates a ramping current equal to half the transient size. When the transient appears, the generated current direction will be reversed. The component size can be further reduced due to smaller current, heating and energy storage requirements. The more compact the circuit, the more likely it could be integrated into future microprocessors.

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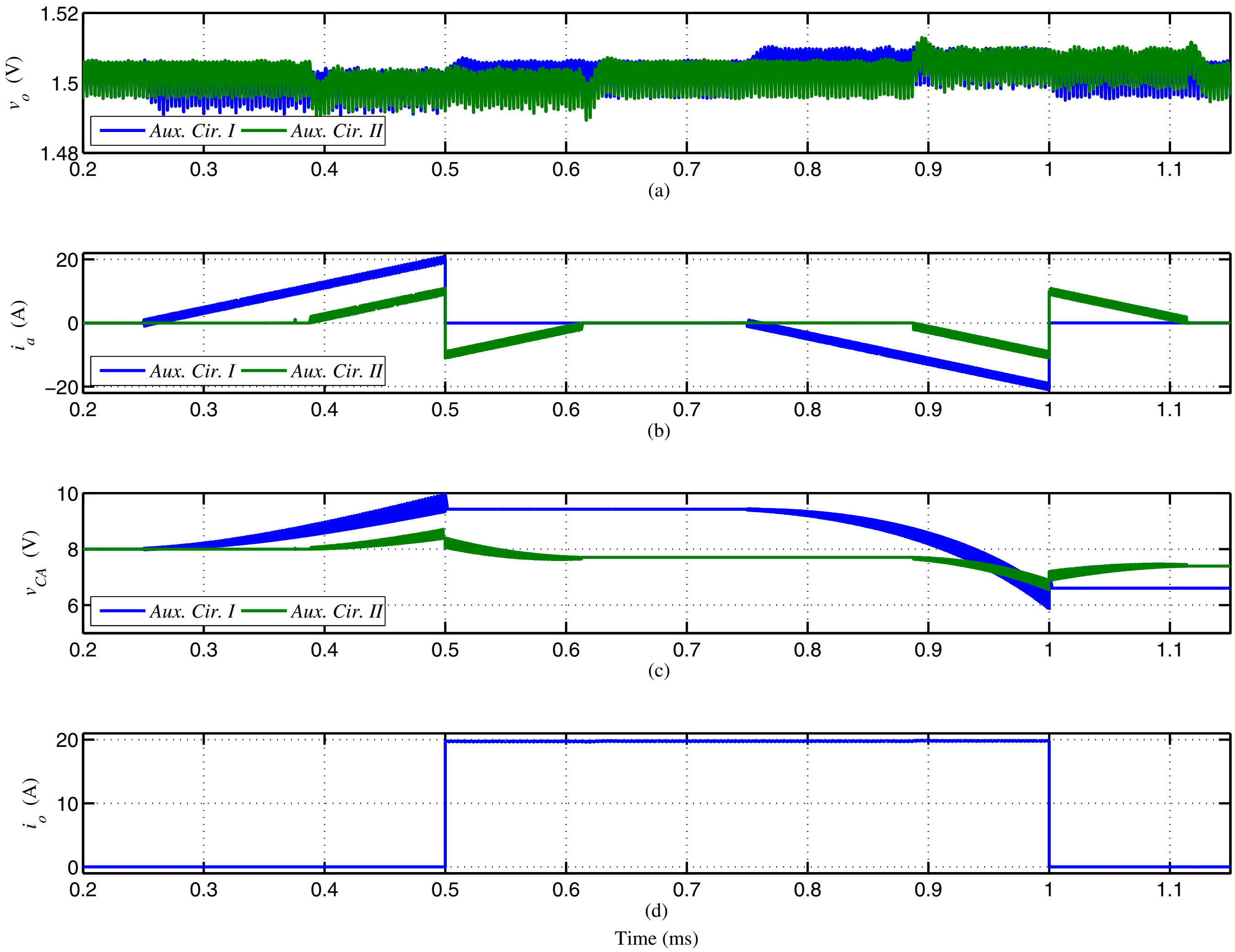

Fig. 7. Simulation waveforms of (a) v_o, (b) i_a, (c) v_{CA} and (d) i_o of two auxiliary circuits.

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