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Pre-Energized Compact Auxiliary Circuit to Buffer Loads from Fast Transients with the Goal of Managing Load-Informed Power

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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 in $v_o$ 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].

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.

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![Fig. 1. Pre-energized auxiliary circuit working with load-informed power.](image-url)
Fig. 2. Auxiliary circuit to provide the transient-size slow sloping current.

Fig. 3. The auxiliary circuit waveforms during four operating stages for \( \Delta I_o \) 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 \( i_o \) 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 auxiliary circuit must receive the load prediction earlier than \( t_1 \) (or \( t_4 \)); otherwise \( i_o \) cannot interact with \( i_{eo} \) 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 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 \(i_o\). The turn-on duty cycle of \(S_3\) will control the current ramping of \(i_{La}\). Assuming \(v_{oa}\) 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 \(-i_o\). The turn-on duty cycle of \(S_5\) will control the current ramping of \(i_{La}\). Assuming \(v_{oa}\) 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 \((\Delta I_o)\), slew rate of mean \(i_o\) \((k_{oad})\), and the value of \(V_{CA3}\) and \(V_{CA4}\), i.e.,

\[
\frac{1}{2}C_A(V_{CA3}^2 - V_{CA4}^2) \geq \frac{V_o \Delta I_o^2}{8k_{oad}} + \frac{1}{8}L_A \Delta I_o^2
\]

where energy loss is neglected. Hence \(C_A\) needs to satisfy

\[
C_A \geq \frac{V_o \Delta I_o^2}{4(V_{CA3}^2 - V_{CA4}^2)} + \frac{L_A \Delta I_o^2}{2k_{oad}}.
\]

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 \(i_o\) limited by 80 A/ms. The switching ripple on \(i_o\) 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>
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<th>Values</th>
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<td>Input voltage</td>
<td>12 V</td>
</tr>
<tr>
<td>Output voltage</td>
<td>1.5 V</td>
</tr>
<tr>
<td>Inductance</td>
<td>0.47 (\mu)H</td>
</tr>
<tr>
<td>Output capacitance</td>
<td>2 (\times) 100 (\mu)F</td>
</tr>
<tr>
<td>Maximum current</td>
<td>20 A</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>300 kHz</td>
</tr>
<tr>
<td>Operation mode</td>
<td>Continuous mode</td>
</tr>
<tr>
<td>Control</td>
<td>Current mode control</td>
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TABLE I

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

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 \(\pm 10\) 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.

REFERENCES

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


