Letters

Zero No-Load Power AC/DC Adapter for Electronic Equipment With Embedded Battery

Byoung-Hee Lee and Gun-Woo Moon

***Abstract*—A zero no-load power (ZNP) ac/dc adapter for electronic equipment with an embedded battery is proposed in this letter. The embedded battery is used as a signal source for the detection of load connection. Depending on the signal of load connection, an operation of the proposed ZNP ac/dc adapter is determined. When the proposed adapter is connected with a load system, the operation of the proposed adapter is the same as that of the conventional ac/dc adapter. While the proposed adapter is disconnected from the load system, the overall proposed adapter is totally turned off. Therefore, the proposed adapter can achieve ZNP consumption. To verify the validity of the proposed adapter, loss analysis and experimental results of 65 W are presented.**

***Index Terms*—AC/DC adapter, burst-mode control, no-load power consumption, standby power.**

I. Introduction

Recently, as the number of electronic device increases such as notebook computer, smart-phone, and smart-pad, demand for the ac/dc adapter is also consistently increasing [1]. The ac/dc adapter is the device that converts universal voltage ac power from wall outlets into a desired voltage dc power needed by various electronic devices. The ac/dc adapter is usually connected to the wall outlets with no regard for connection state of the load system. In other words, the ac/dc adapter is often operated without the attached load system. It is generally called the no-load condition. Therefore, under the no-load condition, the ac/dc adapter just wastes power without any power transfer to the load system. This power consumption is called no-load power or standby power [2]. Standby power has been considered as a waste of electric power and it is typically 5–10% of residential electricity use in most developed countries [3]. Moreover, according to growing concerns about environment and strengthening CO_2 regulation, to reduce standby power consumption, all countries of the world impose legal restrictions on standby power consumption such as Energy Star Program [4] and 1 Watt Plan [5]. Among these, the Energy Star Program requires that the no-load power consumption should be less than or equal to 0.3 W at 0–50 W nameplate output power and less than or equal to 0.5 W at 50–250 W nameplate output power [4].

To meet the standby power regulation, many standby power reduction techniques have been proposed in [6]–[15]. Among several techniques, the burst-mode control [6] and the high-voltage (HV) start-up circuit [8] are commonly employed in the commercial control IC. Moreover, the CAPZero is adopted to reduce the power consumption at discharging resistor R_{dis} for electromagnetic interference (EMI) filter [9]. A no-load power consumption of the conventional ac/dc adapter with these techniques is over several hundred milliwatts [10]–[15]. Although the conventional ac/dc adapter with these techniques meets the no-load requirement [4], [5] with margin, some countries are gradually tightening no-load requirement and some computer manufactures are asking for more stringent no-load requirement, even as low as 30 mW.

In this letter, to meet this requirement and further reduce the power loss under the no-load condition, a zero no-load power (ZNP) ac/dc adapter for electronic equipment with embedded battery is proposed. The proposed method requires an embedded battery in the load (electronic equipment) and an additional wire between the adapter and the load. The embedded battery is used as an independent signal source for the detection of load connection, which is transferred to the primary side to enable the control circuit. By utilizing the load-connection signal, an operation of the proposed adapter is the same as that of the conventional ac/dc adapter during load connection. While the adapter is disconnected from the load system, there is no enable signal for the primary control circuit. Therefore, the overall proposed adapter is completely turned off. As a result, the proposed adapter can reduce the no-load power consumption less than 1 mW. Experimental results of 65 W ac/dc adapter are presented to verify the effectiveness of the proposed adapter.

II. Proposed ZNP AC/DC Adapter

The structure and the operational waveforms of the proposed adapter are shown in Fig. 1(a) and (b), respectively. To realize the proposed adapter, a control-IC ON/OFF block (CIOB) and a monitoring of load-connection block (MOLB) are added to the conventional ac/dc adapter. The operation of the proposed adapter is described as follows.

Turning-off the adapter under the no-load condition is the simple method to reduce the no-load power consumption. However, since the conventional adapter may not recognize the connection of the load system, the conventional adapter regulates v_O even

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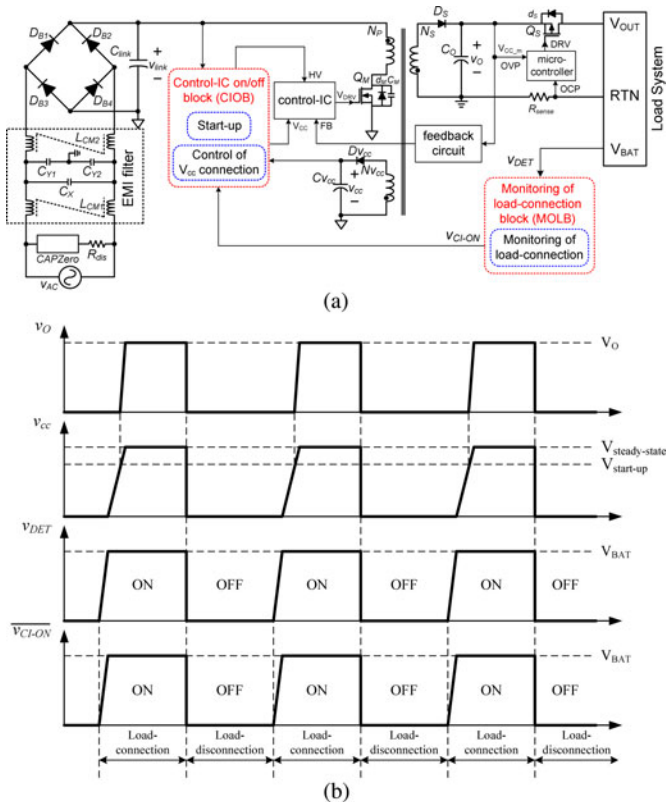

Fig. 1. (a) Structure of the proposed ZNP ac/dc adapter. (b) Operational waveforms of the proposed ZNP ac/dc adapter.

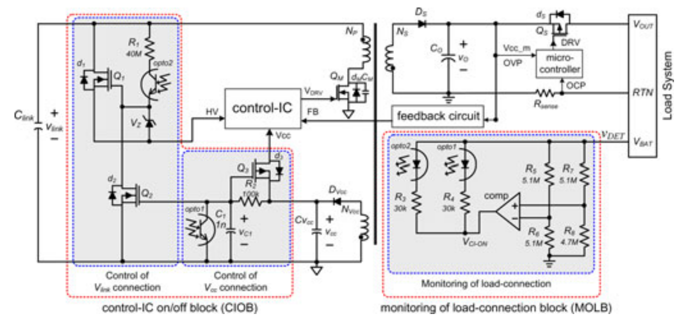

Fig. 2. Implementation example of the proposed adapter.

TABLE I
COMPONENTS LIST OF THE ADDITIONAL PARTS, THE CIOB AND THE MOLB

Part	Value
Comparator Comp	TLV3401
Optocoupler opto1	H11AV1M
Optocoupler opto2	AQV216
NMOS Switch Q_1 and Q_2	STN1HNK60 ($R_{DS(on)} = 8\ \Omega$, $C_{OSS} = 23.5$ pF, $V_{(BR)DSS} = 600$ V)
PMOS switch Q_3	TP0202K ($R_{DS(on)} = 2.1\ \Omega$, $C_{OSS} = 11$ pF, $V_{(BR)DSS} = -30$ V)
Zener diode V_Z	BZX84C15 ($V_Z = 15$ V)

under the no-load condition. Thus, no-load power consumption of the conventional adapter is over several hundred milliwatts. In the proposed adapter, an embedded battery of the load system $v_{\rm BAT}$ is used as a signal source for load-connection signal $v_{\rm DET}$ to monitor the connection of the load system. The operation of the proposed adapter depends on $v_{\rm DET}$.

When the adapter is connected to the load system, $v_{\rm DET}$ and a control-IC turn-on signal $v_{\rm CI-ON}$ are "ON." Then, since the CIOB connects a rectified dc input voltage $v_{\rm link}$ to the HV pin of the control IC and a supply voltage of control IC $v_{\rm cc}$ to the $\rm V_{CC}$ pin of the control IC, the control IC starts to regulate v_O. While the load system is disconnected, since $v_{\rm DET}$ and $v_{\rm CI-ON}$ are "OFF," the CIOB cuts off $v_{\rm link}$ and $v_{\rm cc}$ from the HV pin of the control IC and the $\rm V_{CC}$ pin of the control IC, respectively. Then, the entire proposed adapter is completely turned off and the power consumption of the adapter can be ideally eliminated. Therefore, the proposed ZNP ac/dc adapter can achieve the ZNP consumption. Furthermore, since the proposed adapter manages connecting $v_{\rm cc}$ to the $\rm V_{CC}$ pin of the control IC and $v_{\rm link}$ to the HV pin of the control IC, it can be implemented with any general commercial control IC.

III. IMPLEMENTATION OF THE PROPOSED ZNP AC/DC ADAPTER

Implementation example of the proposed ZNP ac/dc adapter is shown Fig. 2. The components list of additional parts, the CIOB and the MOLB, is described in Table I. Details about the functions of the additional parts are described in the following sections.

A. *Monitoring of Load-Connection Block*

The MOLB monitors whether the load system is connected or not. For this function, the MOLB generates $v_{\rm CI-ON}$ and sends it over to the CIOB when the load system is connected. The MOLB can be realized by using only one comparator and several resistors as shown in Fig. 2.

When the load system is connected to the proposed adapter, since $v_{\rm DET}$ and $v_{\rm CI-ON}$ are "ON," optocouplers $\rm opto_1$ and $\rm opto_2$ are turned ON. Then, the CIOB connects $v_{\rm link}$ to the HV pin of the control IC and $v_{\rm CC}$ to the $\rm V_{CC}$ pin of the control IC. Consequently, the control IC starts its function. Each resistance can be designed to satisfy (1). R_3 and R_4 can be designed considering the operating current of $\rm opto_1$ and $\rm opto_2$

$$\frac{R_6}{R_5 + R_6} > \frac{R_8}{R_7 + R_8}. \tag{1}$$

B. *Control-IC ON/OFF Block*

The CIOB functions to control the connection of $v_{\rm cc}$ and $v_{\rm link}$ in accordance with $v_{\rm CI-ON}$ which comes from the MOLB. Implementation example of the CIOB is also shown in Fig. 2.

As described in Section III-A, since $v_{\rm DET}$ and $v_{\rm CI-ON}$ are "ON" during load connection, $\rm opto_1$ and $\rm opto_2$ are turned on. Then, Q_1 is turned ON by R_1 and V_Z, and $v_{\rm link}$ is applied to the HV pin of the control IC. Consequently, an internal current source of the control IC charges a supply capacitor $Cv_{\rm cc}$, through the antiparallel diode of Q_3, i.e., d_3. After $v_{\rm cc}$ reaches a control-IC start-up level $V_{\rm start-up}$, the control IC is on start-up phase and regulates v_O.

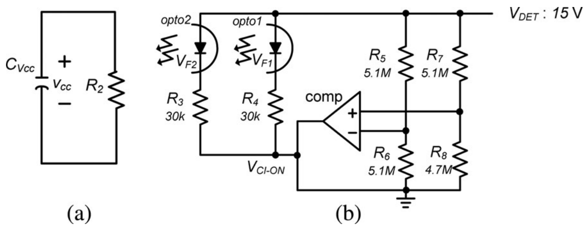

Fig. 3. Approximated circuit of the additional part under load connection: (a) CIOB and (b) MOLB.

While the load system is disconnected, opto$_1$ and opto$_2$ are turned off, because $v_{\rm DET}$ and $v_{\rm CI-ON}$ are "OFF." Then, since C_1 is charged by R_2, Q_2 is turned on and Q_1 is turned off when the voltage of C_1, i.e., v_{C1}, reaches the threshold voltage of Q_2. Simultaneously, Q_3 is turned off when v_{C1} exceeds the sum of $v_{\rm cc}$ and the threshold voltage of Q_3. As a result, $v_{\rm link}$ is disconnected from the HV pin of the control IC and $v_{\rm cc}$ is disconnected from the $\rm V_{CC}$ pin of the control IC. Therefore, the entire adapter including the control IC is turned off until opto$_1$ and opto$_2$ are turned on, i.e., the whole adapter maintains OFF until the load system is connected.

C. Power Consumption of the CIOB and the MOLB

The power consumption of the additional parts can deteriorate the efficiency of the proposed adapter compared to that of the conventional adapter. To obtain the power consumption of the additional parts, the approximated circuit of the additional parts under load connection is described in Fig. 3.

Based on the approximated circuit as shown in Fig. 3 and the components list in Table I, the power consumption of the CIOB, i.e., $P_{\rm CIOB}$, under load connection can be expressed as (2) and it is 2.25 mW. Moreover, the power consumption of the MOLB, i.e., $P_{\rm MOLB}$, can be obtained by (3) and it is 14.1 mW. Therefore, $P_{\rm CIOB}$ and $P_{\rm MOLB}$ slightly decrease the efficiency of the proposed adapter while the adapter is connected to the load system

$$P_{\rm CIOB} = V_{\rm CC}^2 / R_2 \tag{2}$$

$$P_{\rm MOLB} = \frac{V_{\rm DET}^2}{(R_5 + R_6)} + \frac{V_{\rm DET}^2}{(R_7 + R_8)} + \frac{V_{\rm DET}(V_{\rm DET} - V_{F2})}{R_3} + \frac{V_{\rm DET}(V_{\rm DET} - V_{F1})}{R_4} \tag{3}$$

where V_{F1} and V_{F2} are the forward voltage drop of opto$_1$ and opto$_2$, respectively.

When the load system is disconnected, the CIOB and the MOLB are completely turned off. Thus, $P_{\rm CIOB}$ and $P_{\rm MOLB}$ are ideally zero.

IV. Experimental Results

To verify the validity of the proposed ZNP ac/dc adapter, experimental prototype of the proposed adapter and that of the conventional adapter with the burst-mode control are implemented. System specifications of the prototype are described in Table II. Referred to the design solution in [16], the flyback converter and the feedback circuit are designed with the components listed in Table III.

Fig. 4 shows the experimental waveforms of the conventional adapter with the burst-mode control under the no-load condition. With the burst-mode control, v_O is regulated within $\rm V_{o\_ripple}$ even during the no-load condition, because the conventional adapter cannot recognize whether the load system is connected or not. Thus, the time of burst cycle $T_{\rm Burst}$ is 95 ms and the no-load power consumption is 165 mW.

TABLE II
System Specifications of the Prototype

Part	Value
Input voltage V_{AC}	90 $V_{AC,RMS}$ ~ 264 $V_{AC,RMS}$
Output power P_O	65 W (V_O = 17.5 V, I_O = 3.65 A)
Switching frequency F_S	65 kHz
Output voltage ripple V_{O_Ripple}	500 mV_{pk-pk}
Battery voltage V_{BAT}, V_{DET}	15 V

TABLE III
Components List

Part	Value
Bridge diode, D_{B1} ~ D_{B4}	GBL406
Discharge resistor R_{dis}	4.5 MΩ
X-capacitor C_X	220 nF
Link capacitor C_{link}	150 uF
Control-IC	NCP1237
Switch Q_M	SPA11N60C3 ($R_{DS(on)}$ = 0.38 Ω, C_{OSS} = 390 pF, $V_{(BR)DSS}$ = 600 V)
Vcc capacitor C_{Vcc}	47 uF
Transformer turn ratio N_P : N_S : N_{Vcc}	48 : 8 : 7 (core = RM10)
Transformer magnetizing inductance L_M	500 uH
Transformer leakage inductance L_{lkg}	10 uH
Diode D_S	V60100 (V_F = 0.36 V, V_{RRM} = 100 V)
Output capacitor C_O	1360 uF

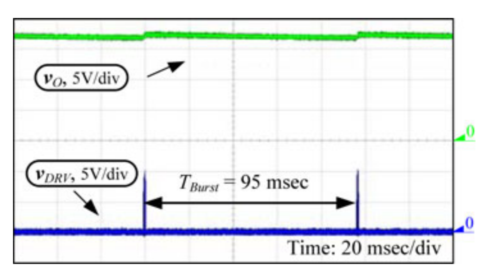

Fig. 4. Experimental waveforms of the conventional adapter with the burst-mode control.

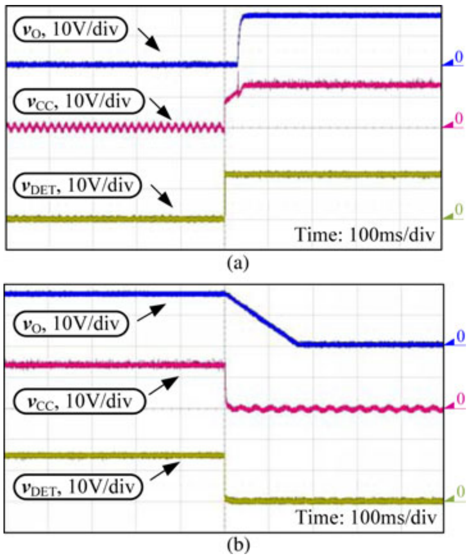

Fig. 5. Experimental waveforms of the proposed adapter (a) from load disconnection to load connection and (b) from load connection to load disconnection.

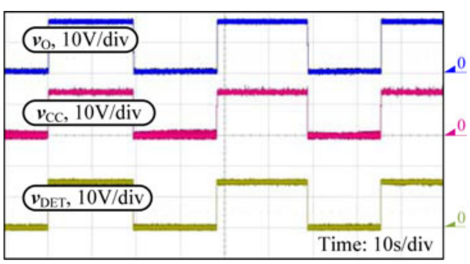

Fig. 6. Experimental waveforms with the repetition of load connection and load disconnection.

Fig. 5(a) and (b) shows the experimental waveforms of the proposed adapter, when the load system is connected with the full-load condition and when the load system is disconnected, respectively. Fig. 6 shows experimental waveforms with the repetition of load connection and load disconnection. As shown in those figures, the proposed adapter is totally turned on and turned off whenever the load system is connected and disconnected. Consequently, the measured no-load power use is greatly reduced below 1 mW at 230 $V_{\mathrm{ac,RMS}}$.

Due to the losses of the CIOB and the MOLB, although the measured efficiency of the proposed adapter is slightly lower under the heavy-load condition and the light-load condition than that of the conventional adapter as shown in Fig. 7, the average efficiency of the proposed adapter is over 91%. Therefore, the proposed adapter sufficiently satisfies the average efficiency requirement of the ac/dc adapter 87% in the latest Energy Star Program [4].

V. Conclusion

The ZNP ac/dc adapter for electronic equipment with embedded battery has been proposed in this letter. The embedded battery is used as the signal source for the detection of load connection. By using the load-connection signal, since the proposed adapter is totally turned off while the proposed adapter is disconnected from the load system, the proposed adapter can achieve zero no-load power. Experimental results of prototype show that the proposed adapter consumes less than 1 mW during the no-load condition. Moreover, the proposed adapter can be implemented with any general commercial control IC with the simple auxiliary circuits, the CIOB, and the MOLB. Therefore, the proposed ZNP ac/dc adapter is expected to be widely used for reducing the no-load power consumption of the ac/dc adapter.

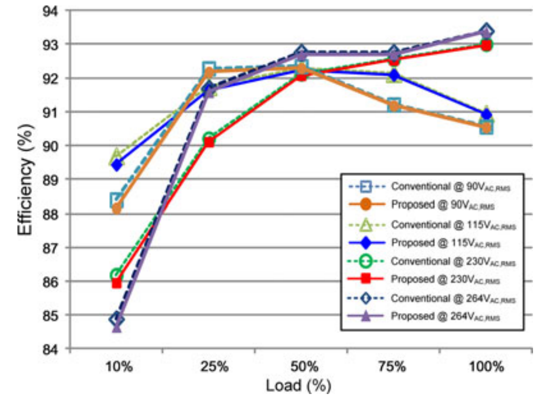

Fig. 7. Measured efficiency according to the variation of input voltage and load condition.

References

[1] Research and Markets, External ac-dc power supplies: Worldwide forecasts, 10th ed.," Apr. 2011.

[2] L. McGarry, "The standby power challenge," in *Proc. IEEE Asian Green Electron. Conf.*, 2004, pp. 56–62.

[3] [Online]. Available: http://standby.lbl.gov/faq.html#watts

[4] [Online]. Available: http://www.energystar.jp/document/pdf/eps_2_0_final_spec.pdf

[5] [Online]. Available: http://www.iea.org/Textbase/subjectqueries/standby.asp

[6] D. M. Dwelley, "Voltage mode feedabck burst mode circuit," U.S. Patent 6 307 356, Oct. 23, 2001

[7] J. M. Esteves and R. G. Flatness, "Adjustable minimum paek inductor current level for burst mode in current-mode dc-dc regulators," U.S. Patent 6 724 174, Apr. 2004.

[8] J. Lei, "High voltage start-up circuit and method therefore," U.S. Patent 5 640 317, Jun. 1997.

[9] Datasheet CAPZero. [Online]. Available: http://www.powerint.com/sites/default/files/product-docs/capzero_family_datasheet.pdf

[10] Y. K. Lo, S. C. Yen, and C. Y. Lin, "A high-efficiency ac-to-dc adaptor with a low standby power consumption," *IEEE Trans. Ind. Electron.*, vol. 55, no. 2, pp. 963–965, Feb. 2008.

[11] K. Y. Lee and Y. S. Lai, "Novel circuit design for two-stage ac/dc converter to meet standby power regulations," *IET Power Electron.*, vol. 2, no. 6, pp. 625–634, Nov. 2009.

[12] B. Y. Chen and Y. S. Lai, "Switching control technique of phase-shift-controlled full-bridge converter to improve efficiency under light-load and standby conditions without additional auxiliary components," *IEEE Trans. Power Electron.*, vol. 25, no. 4, pp. 1001–1012, Apr. 2010.

[13] B. H. Lee, Y. D. Kim, and G. W. Moon, "Single switching double powering converter for reducing power consumption of ac/dc adapter in standby mode," in *Proc. IEEE 8th Int. Conf. Power Electron. ECCE Asia*, May/Jun. 2011, pp. 199–204.

[14] B. C. Kim, K. B. Park, and G. W. Moon, "Sawtooth burst mode control with minimum peak current in stand-by operation of power supply," in *Proc. IEEE 8th Int. Conf. Power Electron. ECCE Asia*, May/Jun. 2011, pp. 474–479.

[15] S. Moon, S. Yun, and G. W. Moon, "A new control method using JFET for an off-line flyback converter with low stand-by power consumption," in *Proc. IEEE 8th Int. Conf. Power Electron. ECCE Asia*, May/Jun. 2011, pp. 480–486.

[16] ON Semiconductor. (2010). Application Note AND8461/D. [Online]. Available: http://www.onsemi.com/pub_link/Collateral/AND8461-D.PD