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Cost-effective Power System with an Electronic Double Layer Capacitor for Reducing the Standby Power Consumption of Consumer Electronic Devices

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Abstract

Commercial home appliances using remotely controlled systems consume electric power while in standby mode to prepare for receiving a remote turn-on signal. The proposed power system can significantly reduce standby power consumption without increasing cost. Furthermore, since a Electronic Double Layer Capacitor (EDLC) is used as an auxiliary power storage element, the life cycle is longer and system reliability can be better than with existing approaches. When the energy of the EDLC is not sufficient for turning on the appliance, the power system charges the EDLC without affecting the main system. The proposed power system is verified with a commercial LCD TV and a 3.93mW standby consumption is obtained. This standby consumption can be regarded as zero standby equipment according to the IEC-62031 standard.

Key words: Electronic Double Layer Capacitor (EDLC), Remote control, Standby power

I. Introduction

Due to the environmental problems caused by higher energy costs, contamination and energy consumption, more studies have been carried out in an effort to reduce standby power consumption. In addition, many nations have recommended reducing standby power consumption. In Korea, a report shows that standby power consumption occupies about 10% of electric energy consumption [1]. Worldwide, standby power accounts for 5-10% of the total electricity consumption in consumer electronic devices. It is responsible for roughly 1% of the worldwide CO2 emissions. [2], [3]. Therefore, the California Energy Commission (CEC) requires a mandatory regulation on standby power consumption. As a result, power supplies lower than 250W should have less than 0.5W. These kinds of requirements are becoming mandatory and increasingly severe in more countries including the EU, USA & some Asian countries to increase efficient use electric energy [4].

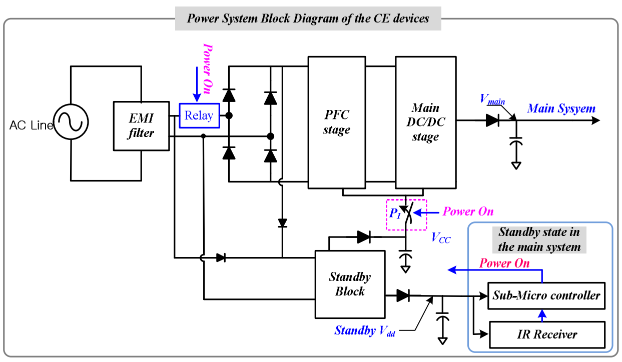

Fig. 1. General power system of the remotely controlled consumer electronic devices.

Fig. 1 shows the general power system of remotely controlled devices. The standby block only works to give power to the sub-micro controller and the infrared (IR) receiver to prepare for turning on a device. When the user push the turn-on button in a remote control, the sub-micro controller makes the power on signal by decoding the IR signal and then transferring the signal to the power system. Then, the power on signal makes the relay switch connect the

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AC line and the Vcc in the standby block wakes up the power factor correction (PFC) stage and the main dc/dc stage. As a result, the system can be turned on by remote control.

Standby power is consumed to prepare for receiving a remote control signal before a user turns on a consumer electronics devices like a digital TV, a home theater, etc. The power consumption is about 2~5mW in a block for standing by to receive a control signal. However, ac input power consumption is over 100mW for supplying a very small amount of energy to electronic devices. Generally, the flyback DC/DC converter is used for the standby power block. New flyback converters have been proposed to obtain high efficiency by soft switching or additional components [5]-[7]. However, since the conventional flyback converter has a simple structure and low cost, many studies have been done to reduce the power consumption of the conventional flyback converter during the standby period and new approaches have been proposed [8]-[17]. Researchers have been able to reduce power consumption by decreasing switching losses and by reducing power consumption in the control-IC, etc. However, a large amount of standby power is still being consumed.

In this paper, a cost-effective standby power structure is proposed to save energy during standby mode in home appliances. The flyback standby power block is removed in the proposed power structure and the ac input is completely, physically disconnected. By using an energy storage element, a Electronic Double Layer Capacitor (EDLC), standby power is provided and the main DC/DC converter is periodically turned on to supply energy to the EDLC. As a result, the proposed power system achieves 3.93mW of standby power consumption without increasing cost, while the standby power consumption is about 100mW in the conventional power systems used in commercialized 46-inch LCD TVs. This standby consumption can be regarded as zero standby equipment according to the IEC-62031 standard.

II. Prior Approaches for Reducing the Standby Power

Fig.2 shows a circuit diagram of the flyback standby power used in consumer electronic (CE) devices. The electromagnetic interference (EMI) filter is used to satisfy safety regulations such as CISPR 22 [20]. In addition, the discharge resistor, R_{dis}, is needed to discharge the x-capacitor, C_x, for protection from electric shock. If users do not turn on the device, relay 1 is disconnected and the standby power is given by a half wave rectification with D_S. The controller-IC integrated with a FET switch regulates the standby V_{dd} by the feedback signal from the feedback circuit. Burst-mode control is widely used for reducing power consumption in either the light load or no load conditions [8]-[11]. Since the standby state is the light load condition in CE devices, the standby flyback circuit uses the burst-mode control as shown

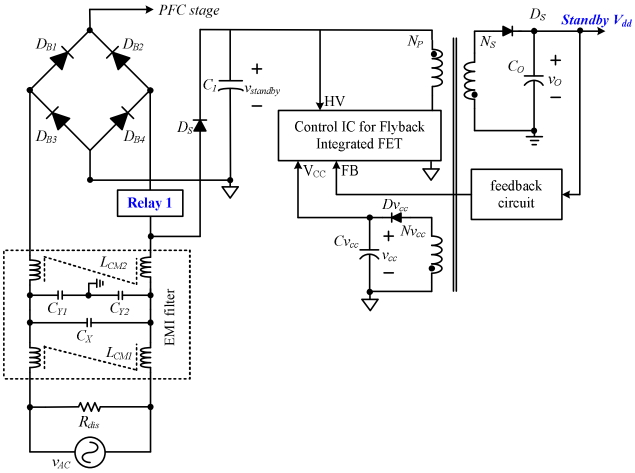

Fig. 2. Circuit diagram of the flyback standby power.

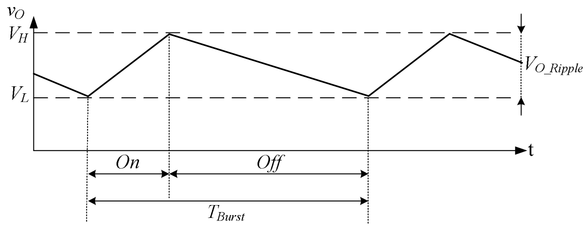

Fig. 3. Operational waveform of the burst-mode operation.

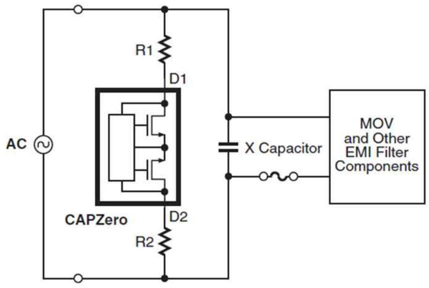

Fig. 4. CAPZero scheme.

as shown in Fig. 3. As the control IC is worked and not worked by the band gap from V_L to V_H, the switching loss and power for driving the control IC can be significantly reduced. However, a lot of power is still consumed to regulate the output voltage in the feedback circuit, the EMI filter, the discharge resistor, etc.

Since the control IC power is supplied by the auxiliary winding of a transformer, another approach is to reduce the operating current of the control IC [12]. The IC operation current is reduced by decreasing the feedback current which is a large amount of the total operation current. In addition, the discharge resistor for the x-capacitors in the EMI filter is a crucial component. The energy stored in the x-capacitors has to be discharged naturally when the CE devices are disconnected from the power outlet to protect humans from electric shock. A commercialized method is uses a discharge resistor in parallel with the x-capacitors, which results in a large additional power loss as the CE devices are inevitably connected to the power line. The discharge resistor should be designed based on the discharge time and power consumption. A marginal discharge time must be secured to discharge the x-capacitors to a safe level which is not harmful to the human body. A commercial IC is proposed to eliminate the addition loss in the discharge EMI resistor, as shown in Fig. 4 [10]. However, the additional IC is needed and the cost is increased. Other studies have reported that an additional storage element is used for the output capacitor in the standby power supply [14]. By monitoring the output voltage of the output capacitor, the AC input is connected or disconnected. However, since the monitoring system is in the secondary side of the standby power supply, additional parts such as a photo coupler and additional voltage sources are needed. As a result, the system is complex and has a high cost.

Some researchers have used external energy sources to completely remove the standby power [15]-[18]. Photovoltaic (PV) cells are used for harvesting light energy but the PV cells cannot give standby power in a dark room [15]. Another approach is using a laser diode in the remote controller to transfer energy to the PV cells in the CE system [16]. However, the laser diode consumes a large amount of power and is very expensive.

III. THE PROPOSED COST-EFFECTIVE POWER SYSTEM

Fig. 5 shows the proposed cost-effective power system for reducing standby power. The conventional flyback converter is used to supply the very small standby power, 2~5mW, and many studies have been carried out to improve the power conversion efficiency under light load and no load conditions. However, although many approaches have been tried, the power conversion efficiency is very low and a lot of energy is consumed or the cost is increased. The proposed system uses energy storage elements such as a battery and the an EDLC, which are charged when the power conversion efficiency is high. In addition, the conventional standby block is removed to restrain the cost from increasing. As shown Fig. 5, the proposed power system uses an EDLC with an additional storage element and a standby micro controller is used for monitoring the charge state of the EDLC. A latch-type relay is used to charge the EDLC when it is discharged entirely and unable to receive the turn-on remote signal and the AC power outlet is disconnected. This approach is used because the latch-type relay can keep the final state without driving energy. The operation is as follows:

Stage 1 (Operation mode): The energy in the EDLC is used in the standby micro controller for monitoring the charge state of the EDLC. When the user turns on the CE device with the remote control, the standby micro controller detects only the IR signal and turns on the path switch, S1, which connects the EDLC energy to the sub-micro controller in the main system to encode the remote control's signal. Then the sub-micro controller gives the power on signal to the standby micro controller and the standby-micro controller makes the latch-type relay connect to the power outlet. At this point, normal operation is done. The EDLC is fully charged during stage 1. After the EDLC is fully charged, the charger supplies power to the Sub-Micro controller and the IR receiver so that the EDLC can sustain the state of fully charging.

Stage 2 (Charging standby mode): When the EDLC is discharged below some level, the standby micro-controller

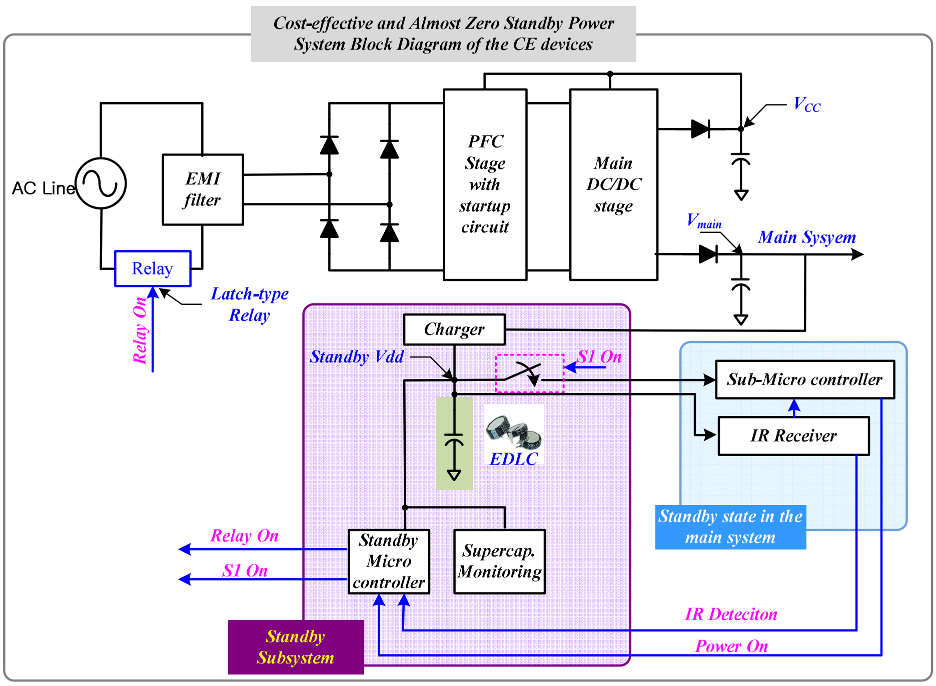

Fig. 5. Proposed cost-effective power system.

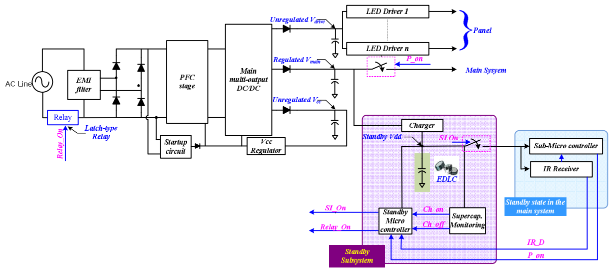

Fig. 6. LCD TV power system using the proposed cost-effective power system.

TABLE I
KEY PARAMETER AND TOPOLOGY OF LCD TV POWER SYSTEM COST-EFFECTIVE POWER SYSTEM

Classification	Description
PFC stage	Boundary conduction mode boost converter
Main multi-output stage	LLC resonant converter
LED Driver	Boost converter
Vcc regulator	KIA7815
Charger	TPS84620
Average power in TV-on	100W
Standby Vdd	6.7V
AC input	90VAC~264V (47Hz~63Hz)

turns on the latch-type relay. The main power stage is turned on and the main dc/dc converter can charge the EDLC. Although the main power stage is turned on, the power is not supplied to the TV since the main system is not turned on by the remote control. Stage 2 is finished when the EDLC is fully charged.

Stage 3 (Standby mode): When the EDLC is fully charged, the latch-type relay is turned off. Power is only consumed in the standby-micro controller and the IR receiver. Since the standby-micro controller is operated in a deep sleep mode, the power consumption is very small. When the power consumption is below 5mW, this mode can be regarded as zero standby power consumption by the IEC-62031 standard.

Stage 4 (Off mode): When the ac line is lost, the EDLC is discharged entirely. By stage 2, the latch-type relay is continuously turned on and the CE power system is connected with the AC power outlet. Therefore, energy can be charged in the EDLC when the ac line is alive again and the system can prepare to receive the remote control signal to turn on the CE device. When the energy is fully charged in the EDLC, stage 4 returns to stage 3.

A battery is another solution for the storage element. However, batteries such as Li-ion and Ni-Cd cannot be used for a long time because their life time is decayed by charging and discharging cycles. The EDLC or the super capacitor has

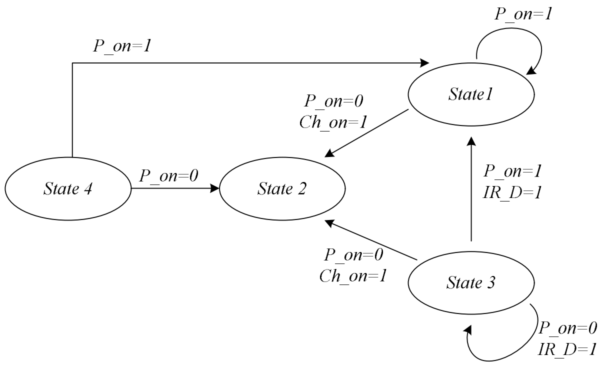

Fig. 7. State diagram of the standby-micro controller.

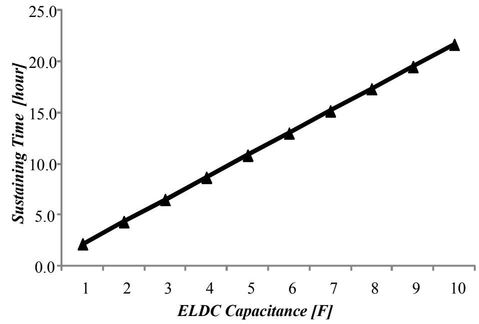

Fig. 8. Standby sustaining time according to the EDLC.

a longer life cycle and increased safety [19]. In addition, the volume and the cost of a Li-ion battery can be disadvantages.

IV. SYSTEM DESIGN CONSIDERATION

Fig. 6 shows an LCD (Liquid Crystal Display) TV with the LED backlight unit power system using the proposed cost-effective reduced standby power system. Based on the commercialized power structure, this chapter shows the standby-micro controller algorithms and the design considerations of the EDLC operation voltage and capacity according to the number of charging times per day.

A. Stage Description of the Standby-micro Controller

Two input signals and four output signals are used in the standby-micro controller. *S1_on* is active when the standby-micro controller detects an IR signal with a signal *IR_D*. After that, the *P_on* signal is given from the sub-micro controller in the main system and stage 1 begins. However, if the *P_on* signal is not given until a designed interval, the state comes back to stage 3. The EDLC can be charged by the main dc/dc converter when the signal *Ch_on* is high and the signal *Relay_on* is high. Since the *P_on* signal is not high, the power cannot be supplied to the main system and the EDLC is charged without disturbing the main system. The operation can be shown with a state diagram according the input signal,

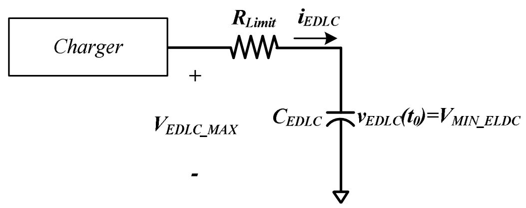

Fig. 9. Equivalent circuit for charging the EDLC.

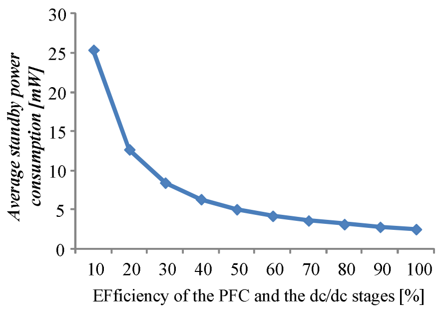

Fig. 10. Average standby power consumption.

TABLE II
EXPERIMENTAL SPECIFICATION OF THE PROTOTYPE

Part	Value
Standby-Micro controller	PIC16F1827
EDLC	7.5V/5F
S1	MDD1752
Monitoring	LM193
Latch-relay	FTR-F1L
Charger	TPS84620
Start-up circuit	BSS126
AC input	220VAC
System standby power	1.38mW

as shown in Fig. 7.

B. Design Consideration of the EDLC

The electrical design of the EDLC is related to the standby power consumption and the sustaining time during which the standby power is supplied from the EDLC without a connection to the AC input. The starting voltage of the EDLC which charges the EDLC is started by the AC input. It can be determined with a sufficient voltage level to drive the latch-type relay. When V_{EDLC_MIN} is the driving minimum EDLC voltage for the latch-type relay driving, V_{EDLC_MAX} is the charging maximum EDLC voltage. The sustaining time, T_{zero} can be determined by:

$$T_{zero} = \frac{C_{EDLC}(V^2_{ELDC\_MAX} - V^2_{ELDC\_MIN})}{2P_{std}} \tag{1}$$

where the C_{EDLC} is the capacitance of the EDLC and P_{std} is the standby consumption of the main system. When P_{std} is 2mW and V_{EDLC_MIN} and V_{EDLC_MAX} are 3.7V and 6.7V each, T_{zero} can be obtained, as shown in Fig. 9, according to the capacitance. As shown in Fig. 9, the sustaining time without charging the EDLC is about 11 hours with the 5F capacitance and the charging operation is two times if the user does not turn on the CE device for a day. Another design factor is the power consumption during the charging time of the EDLC. The PFC stage and the dc/dc stage are active to charge the EDLC in the proposed system. If the power conversion efficiency of the two stages is high, the charging time will be short and the energy for charging the EDLC is decreased. The charging time can be determined with a simple RC circuit, as shown in Fig. 9. The charger regulates the output voltage in V_{EDLC_max}. The charging time, T_c, can be obtained as follows:

$$T_c = R_{Limit} C_{EDLC} In \frac{V_{EDLC\_MAX}}{V_{EDLC\_MIN}} \tag{2}$$

where R_{limit} is the current limit resistor. The total power, P_{ch}, to charge the EDLC can be obtained as follows:

$$P_{ch} = \frac{1}{T_c} C_{ELDC} V^2_{EDLC\_MAX} \left(1 - e^{-\frac{T_C}{R_{Limit} C_{EDLC}}} \right) \tag{3}$$

The average standby power of a CE device with the one charging the EDLC can be obtained as follows:

$$P_{std\_avr} = \frac{P_{ch} T_C / \eta_{two}}{T_c + T_{zero}} \tag{4}$$

where η_{two} is the efficiency of the PFC and the dc/dc stages. Fig. 10 shows the average standby power according to η_{two} when P_{std} is 2mW, V_{EDLC_MIN} and V_{EDLC_MAX} are 3.7V and 6.7V, respectively, C_{EDLC} is 5F, and R_{limit} is 200Ω. As shown in Fig. 10 the average standby power is about 5mW when the efficiency of the two stages is about 50%. This estimated result is much smaller than the standby power consumption of the conventional power system to give 2mW.

V. EXPERIMENTAL RESULTS

A prototype is implemented with a commercialized LCD TV with LED backlighting. The conventional power system with the flyback standby circuit consumes about 98mW to supply the real standby power, and 2.32mW in the micro controller and IR receiver. Fig. 11 shows the printed circuit board (PCB) with the proposed standby subsystem and the main parts, as shown in Table 2. The standby micro controller is used to turn on and off the latch type relay and S1 with a very cheap PIC16F1827. The startup circuit is implemented with a depletion FET, BSS126 and plays a role in waking up the PFC and main dc/dc stages. After the two stages are active, the startup circuit is not operated. The charge uses the buck dc/dc converter with the integrated FET IC due to its

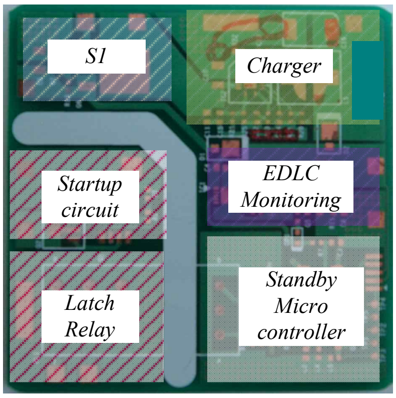

Fig. 11. PCB for the prototype of the proposed standby subsystem.

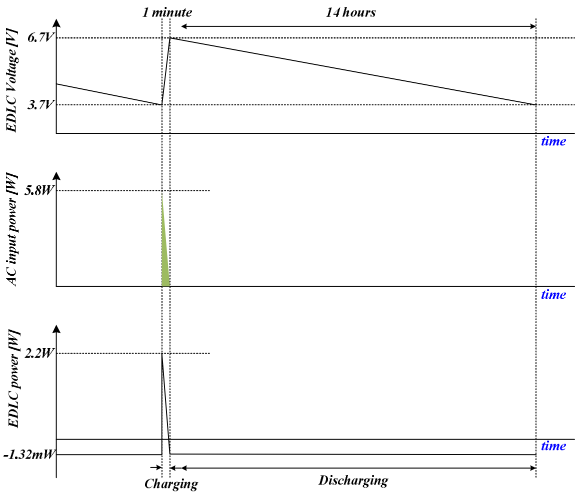

Fig. 12. Experimental result.

low cost and small volume. Power consumption is measured when the AC input is 220VAC because the efficiency of the PFC stage is at its worst under a light load condition. The real standby power consumption is reduced to 1.38mW by disconnecting the power to the micro controller from the switch, S1, as shown in Fig 6. The proposed power system with the 7.5V/5F EDLC can maintain the standby mode for 14 hours without any ac line power consumption and the EDLC is charged for one minute, as shown in Fig 12. The charging time is about 1 minute. Since the total energy is 55mWh to fully charge the EDLC, the average power consumption is 3.93mW during 14 hours. This power consumption can be almost considered as zero standby power consumption by the IEC-62031.

VI. CONCLUSIONS

A new power system and structure for consumer electronic devices are proposed in this paper. The proposed system can remarkably reduce standby power consumption without increasing cost. In addition, an EDLC is used for the reliability of the product. Using the prototype with a commercialized LCD TV, the proposed power system achieves 3.93mW standby power consumption without increasing the cost. This proposed standby power system can be an eco-solution for CE devices using a remote control.

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