Design and Implementation of Zero Standby Power using Fixed-Frequency Flyback Converter

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ABSTRACT

This study presents a zero-standby power solution for household appliances, addressing the persistent issue of power consumption when devices remain plugged in. The research aims to reduce standby power usage through the implementation of fixed-frequency flyback converter technology. The system integrates a fixed-frequency flyback controller, a current sensor, and a passive infrared (PIR) sensor. The flyback converter supplies the necessary power to the sensors. In contrast, the PIR sensor detects motion to activate an AC relay when a user approaches, and the current sensor maintains power until the user finishes their task. The study demonstrated that standby power consumption was reduced to 70-90mW across a wide input range of 85Vrms to 265Vrms, with an overall efficiency between 80-95% at a 1.5kW load. Despite the promising results, challenges were encountered, such as the PIR sensor's accuracy in detecting light movements. Despite these limitations, the design still has a substantial positive effect on reducing household energy consumption. The proposed system offers practical implications for consumer electronics, paving the way for more energy-efficient household appliances.

Keywords: *Standby Power, Zero, Appliances, PIR, current sensor*

INTRODUCTION

A wide range of household appliances, including televisions, microwave ovens, and air conditioners, continue to consume power even when switched off or not in use. This constant power draw, known as "standby power" or "vampire electricity," contributes significantly to global energy waste. Standby power can account for up to 10% of a household's electricity consumption, and globally, it represents a considerable portion of residential energy use. According to the International Energy Agency (IEA), standby power usage is responsible for approximately 500 terawatt-hours of electricity consumption annually, which equates to 1% of global carbon dioxide emissions. In countries like the United States, this waste costs consumers billions of dollars each year and significantly contributes to environmental degradation. For example, in Australia alone, residential standby power consumption has been estimated to cost $1.1 billion annually and contribute to nearly 5.7 million tons of carbon dioxide emissions (Chang et al., 2013). These statistics highlight the urgent need to develop solutions that address the economic and environmental impacts of standby power consumption.

Several techniques have been developed to minimize standby power consumption in household appliances. One approach involves RFID technology, which eliminates standby power but requires a large directional antenna and a battery-driven relay (Chen et al., 2010). Another method utilizes power sockets with photovoltaic (PV) cells for energy harvesting, combined with passive infrared (PIR) sensors to detect user presence (Tsai et al., 2010). However, these systems have limitations, such as continued power consumption in dark environments and reliance on user interaction to activate the socket. Solar-powered systems, while effective in certain conditions, are also limited by light availability, reducing their overall efficiency (Wallada et al., 2012).

To address these challenges, this study proposes a novel solution using Fixed-Frequency Flyback Converter technology to achieve zero standby power consumption. The design integrates a flyback converter with a current sensor and PIR sensor, enabling it to be seamlessly integrated into any household appliance via an AC socket. The main objectives of this research are to 1) Design a fixed-frequency controller for the flyback converter; 2) Develop a zero standby power system incorporating the flyback converter, current sensor, and PIR sensor, with circuit simulation using Simetrix; and 3) Implement a printed circuit board (PCB) prototype and evaluate its performance at low (85 Vrms) and high (265 Vrms) line voltages.

This design aims to significantly reduce standby power consumption, providing a practical and scalable solution for households. By utilizing tool such as Simetrix and relying on readily available components, the proposed system offers a cost-effective and efficient method to reduce the environmental and economic impacts of standby power.

LITERATURE REVIEW

In today's focus on energy efficiency, reducing standby power—energy consumed by devices while off but plugged in—is crucial due to its significant impact on energy waste and environmental sustainability. This review explores recent research and advancements in minimizing standby power, focusing on Switch-Mode Power Supplies (SMPS), Flyback Converters, and the VIPER06 controller.

Standby power, or phantom power, is used for functionalities like remote controls and clock displays, but often results in unnecessary energy waste (Siderius et al., 2006). While individual appliance consumption may be low, cumulative household standby power can be substantial, as shown in Table 1.

Table 1

Approximate Residential Standby Power Consumption per Household

Appliances	Standby Mode Power (W)	Average Active Mode Power (W)
TV set	0.1-10	80
VCR	3-12	40
CD Player	1-5	30
DVD Player	1-7	40
Video Games	1-8	25
Digital Sound System	1-3	30
Satellite Dish Box	5-11	20
Cable TV dish box	5-12	20

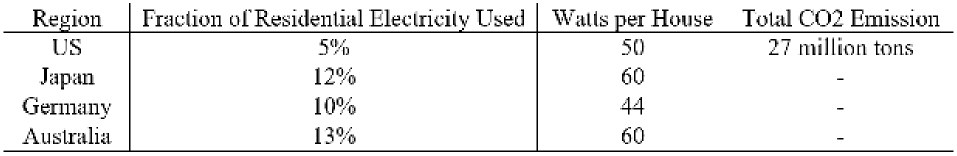
Appliances like TVs and cable boxes use small standby power (0.1-12 W), but it accumulates, leading to notable energy waste.
Source: (Chakraborty et al., 2011)

The data indicates that although individual appliance standby power is low, the aggregate effect within a household is significant.

Globally, standby power impacts significantly. For instance, in the U.S., it accounts for about 7% of residential electricity use, with similar figures in other developed countries, leading to millions of tons of CO2 emissions annually (Chakraborty et al., 2011). Table 2 provides a snapshot of global standby power statistics.

Table 2

Global Residential Standby Power Consumption



Region	Fraction of Residential Electricity Used	Watts per House	Total CO2 Emission
US	5%	50	27 million tons
Japan	12%	60	-
Germany	10%	44	-
Australia	13%	60	-

Global standby power usage varies by region. U.S. households average 50 watts, producing around 27 million tons of CO2 annually.

Source: (Chakraborty et al., 2011)

Innovative solutions to reduce standby power include RF energy systems, photovoltaic power sockets, and light energy-based systems, each with specific limitations (Chen et al., 2010; Tsai et al., 2010; Wallada et al., 2012). One notable solution involves using RF-modulated signals to operate household appliances, eliminating standby power consumption. RFID systems use passive tags to recover energy but face challenges like large antennas and short ranges. Additionally, photovoltaic power sockets with PIR sensors reduce standby power but can be less effective in low light.

Switch-Mode Power Supplies (SMPS) are efficient power units used across electronics, initially developed for military applications but now prevalent in consumer electronics due to their compact design and efficiency (Kim et al., 2011). SMPS units use switching regulators to convert power with minimal heat dissipation. Figure 1 illustrates the block diagram of an existing Switched-Mode Power Supply (SMPS).

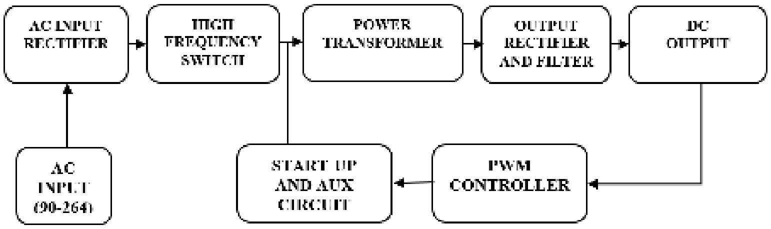


Figure 1. **Block Diagram of existing Switch-Mode Power Supply (SMPS)**

Source: (Kim et al., 2011)

This block diagram shows the AC input supply is initially rectified and then filtered by an input reservoir capacitor to produce a rough DC input supply. This DC level can fluctuate significantly due to variations in the mains voltage. To address this, the input capacitor must have a relatively large capacitance to sustain the supply in case of severe voltage drops in the mains (Kim et al., 2011). The SMPS design includes components such as the AC input rectifier, power transformer, and PWM controller, which work together to convert and regulate electrical power.

The system's efficiency is enhanced through complex circuit designs that reduce heat and improve performance.

The Flyback Converter, known for its cost-effectiveness and meeting 80 PLUS efficiency standards, is particularly effective in low-power applications (Singh et al., 2010). The VIPER06 controller enhances Flyback Converter performance with high efficiency and reliability (VIPER06 datasheet, 2024). Table 3 compares various converter specifications, highlighting the Flyback Converter's efficiency.

Table 3

Specifications of different converters

Topology	Power Range (W)	Vin (dc)Range	In/Out Isolation	Typical Eff(%)
Buck	1000-0	40-5	No	78
Boost	150-0	40-5	No	80
Buck-Boost	150-0	40-5	No	80
IT Forward	150-0	500-5	Yes	78
Flyback	150-0	500-5	Yes	80
Push-pull	1000-100	1000-50	Yes	75
Half Bridge	500-100	1000-50	Yes	75
Full Bridge	+2000-400	1000-50	Yes	73

The Flyback converter handles 0-150 W, with a 5-500 V input range, provides isolation, and has 80% efficiency, making it ideal for low to mid-power applications.

Source: (Brown, 2001)

METHODOLOGY

I. Materials, Equipment, Software

1. **Prototype Materials: A** detailed list in Table 4 for the components used in the prototype is provided. Each component is specified with its reference, quantity, symbol, and description to facilitate replication and understanding of the prototype construction.

Table 4

Bill of Materials

Part Reference	Quantity	Component symbol	Description
2KΩ	1	R2	Resistor
10KΩ	1	R1	Resistor
NPN	1	Q1	Transistor
na	1	D1	Diode
10KΩ	2	R9, R12	Resistor
1K	3	R7, R8, R11	Resistor
4.75KΩ	1	R10	Resistor
315KΩ	1	R6	Resistor
IC	1	U1	Comparator
NMOS FET	2	M1	Transistor
MB10S	4	D9-D12	Diode (bridge)
10KΩ	1	R4	Resistor
4.7KΩ	1	R5	Resistor
102Ω	1	R3	Resistor
10uF, 16V	1	C1	Electrolytic cap
na	1	CT	Current transformer
NPN	1	Q2	Transistor
1KΩ	1	R23	Resistor
na	1	D2	Diode
22uF, 10V	1	C2	Capacitor
10KΩ	1	R13	Resistor
na	1	L1, L2, and L3	Transformer
IC	1	U2	Controller

A detailed component list for easy replication of the prototype.

Source: Author

2. Equipment/s

Voltage Source:

DC source: Chroma Programmable DC Power Supply
AC Source: Chroma Programmable AC Source Model 61505 and California Instruments Model

Measuring Equipment:

Oscilloscope: Tektronix DPO 4034 Digital Phosphor Oscilloscope
Multimeter: Fluke 73 III Multimeter and Agilent 34401A 6.5 Digit
Power Meter: Voltech PM100 Single Phase Power Analyzer
Power Meter: Yokogawa WT 210
Voltage Probes: Tektronix P6139A
Current Probe: Tektronix TCP 0030 and TCP312

Load and Soldering:

Electronic Load: Chroma 6314 and Chroma 63108 DC Electronic Load
Shunt resistor: rated 25mΩ, 1A
Soldering Iron
Soldering Lead

3. Software

Simetrix - is a circuit simulation tool used in this study to model and validate the performance of the Fixed-Frequency Flyback Converter and related components. It enabled testing under various conditions, optimizing the design before physical implementation, and ensuring efficiency in reducing standby power consumption.

II. Design Framework

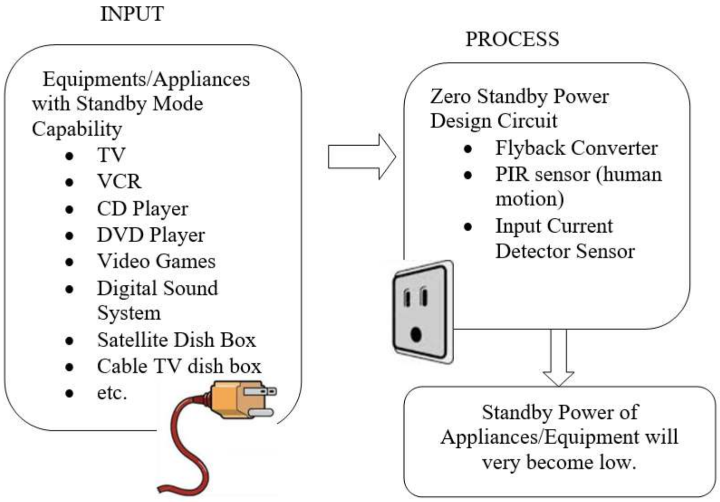


Figure 2. **Conceptual Framework of the design and Implementation of zero standby power using Fixed-Frequency Flyback Converter**
Source: Author

III. Research Flow of Zero Standby Power Design

The design and implementation process follows a structured flow, as illustrated in Figure 3. This fl … of the Fixed-Frequency Flyback Converter, current sensor, a … he step-l … ection through f

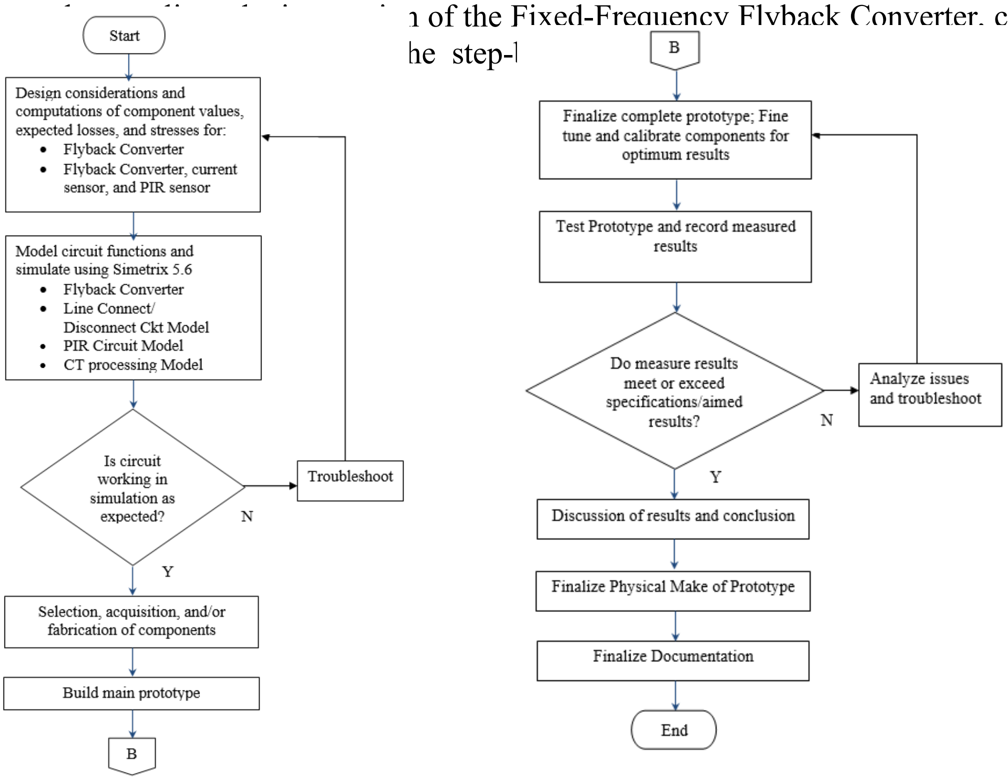


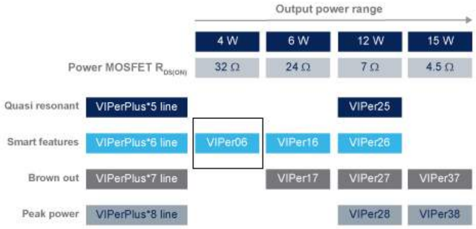
Figure 3: **Research Flow of Design and Implementation of Zero Standby**
Source: Author

IV. Rationale for Component Selection

A Fixed-Frequency Flyback Converter was chosen for its energy efficiency and ease of use in low-power applications. Its fixed-frequency operation simplifies EMI filtering and control across varying line voltages (85-265 Vrms). Although other converters offer lower switching losses, the fixed-frequency design's simplicity and component availability made it more suitable. The VIPER06 controller was selected for its integrated protection, low component count, and compatibility with both low- and high-line voltages, reducing design complexity.

V. Selection of the Right Controller

Choosing a Flyback controller usually depends on specific application and other design consideration such as cost, design form factor and ease of design. Figure 4 shows a selection guide using ST Microelectronics solution for fixed-frequency Flyback with regards to its maximum output power. The Viper06 has an integrated solution that offers low parts count and easier implementation.



Output power range →

		4 W	6 W	12 W	15 W
Power MOSFET $R_{DS(ON)}$		32 Ω	24 Ω	7 Ω	4.5 Ω
Quasi resonant	VIPerPlus*5 line			VIPer25	
Smart features	VIPerPlus*6 line	VIPer06	VIPer16	VIPer26	
Brown out	VIPerPlus*7 line		VIPer17	VIPer27	VIPer37
Peak power	VIPerPlus*8 line			VIPer28	VIPer38

Figure 4: **STMicroelectronics Fixed-Frequency Flyback Controller**
Source: (STMicroelectronics, 2009)

VI. Prototype Development

The prototype was constructed according to the detailed schematic diagram provided in Figure 5. The PCB design includes key components such as resistors, transistors, diodes, capacitors, and transformers. The assembly process was straightforward, though special attention was needed for heat dissipation, especially around the transformer, to prevent overheating during extended operation.

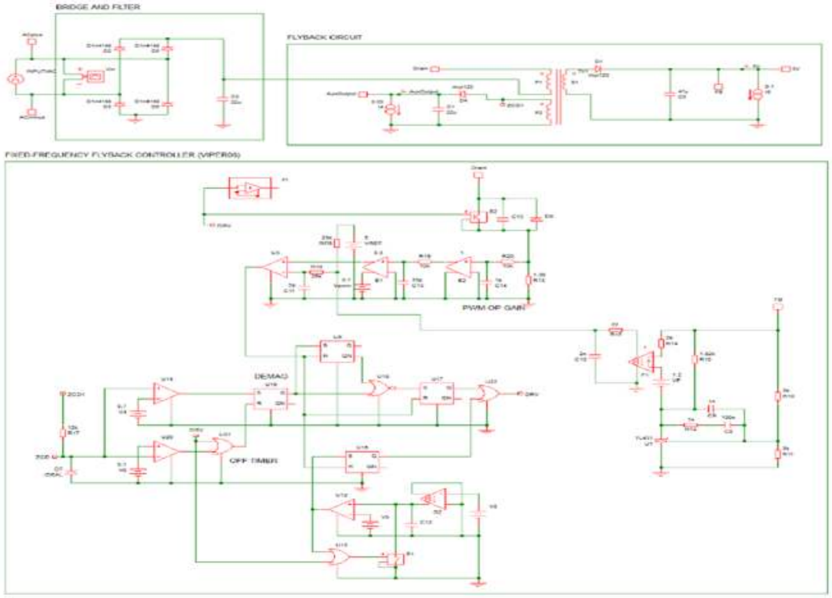


Figure 5. **Complete schematic diagram of zero standby power using Fixed- Frequency Flyback Converter**
Source: Author

VII. Limitations and Challenges

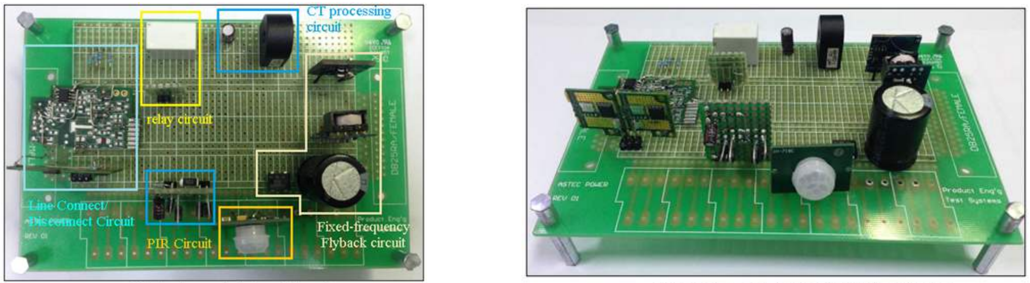
During the development of the prototype, several challenges were encountered. One significant limitation was the sensitivity of the PIR sensor in detecting light movements, which led to occasional false triggers in environments with minimal activity. This was mitigated by adjusting the sensor's sensitivity range, although it introduced a trade-off between detection accuracy and power consumption. Additionally, the current transformer posed challenges in terms of calibration, requiring precise tuning to ensure accurate readings across different load conditions. Despite these challenges, the overall design met its objectives for reducing standby power consumption.

VIII. Simulations

Simetrix simulations are used to validate the theoretical calculations and design parameters. Simulations include current transformer processing circuit outputs under different conditions.

IX. Pictorial Diagram of Design and Implementation

The main board in Figure 6 is depicted from multiple angles to provide a comprehensive view of the design. The top view and front-side view of the main board are included to highlight the layout and component placement.



Main board (Top View)

Main board (Front-Side View)

Figure 6. **Pictorial Diagram of the Design**
Source: Author

X. Actual Measurements on the Prototype Circuit

Measurements taken during the testing phase are documented to assess the performance of the Fixed-Frequency Flyback Converter. These measurements include output voltage regulation at various load conditions, burst mode during standby, and the performance of the line connect/disconnect circuit. The results demonstrate the effectiveness of the design in maintaining voltage stability and minimizing power consumption during standby mode.

XI. Testing the PIR Sensor Circuit

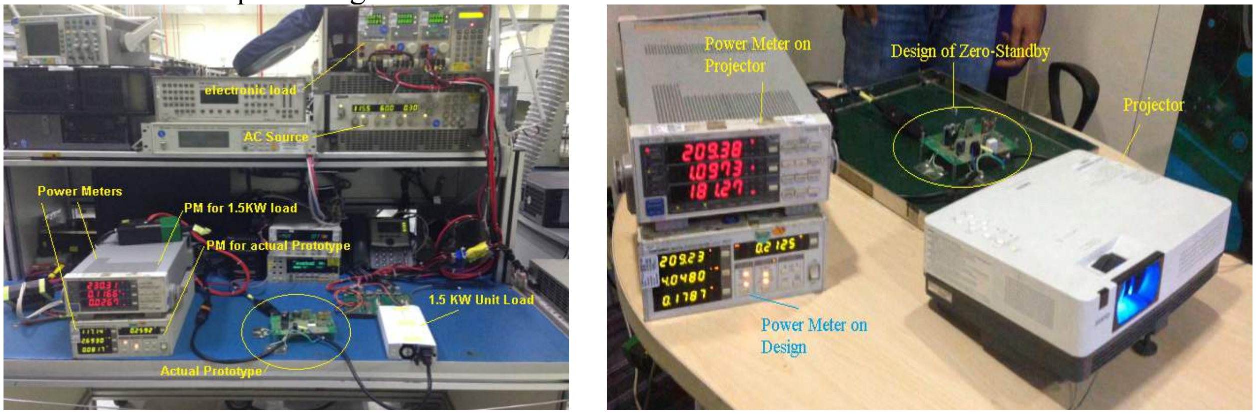
The PIR sensor circuit is tested for stability and motion detection capabilities. The process flow for testing the PIR sensor circuit design is outlined, showing stability time and motion detection measurements. The stability time of the PIR sensor is approximately 18.1 seconds, after which it reaches a constant state.

XII. Efficiency Measurements

Efficiency measurements are conducted on the design using a 1.5 kW load. The data collected includes input power, output voltages, and currents, which are used to calculate the efficiency of the design. The efficiency is compared against the target standard, showing that the prototype meets or exceeds the expected performance levels.

XIII. Standby Power Measurements

Standby power measurements with the setup in Figure 7A are performed with and without the design, using a 1.5 kW load. The measurements indicate significant improvements in standby power consumption with the design, averaging a 98% reduction in standby power across various input voltages.



(A) (B)

Figure 7. **Power Set-up and Measurement (A) 1.5KW Load (B) 200W Projector**
Source: Author

IX. Time-Based Measurement of Standby Power

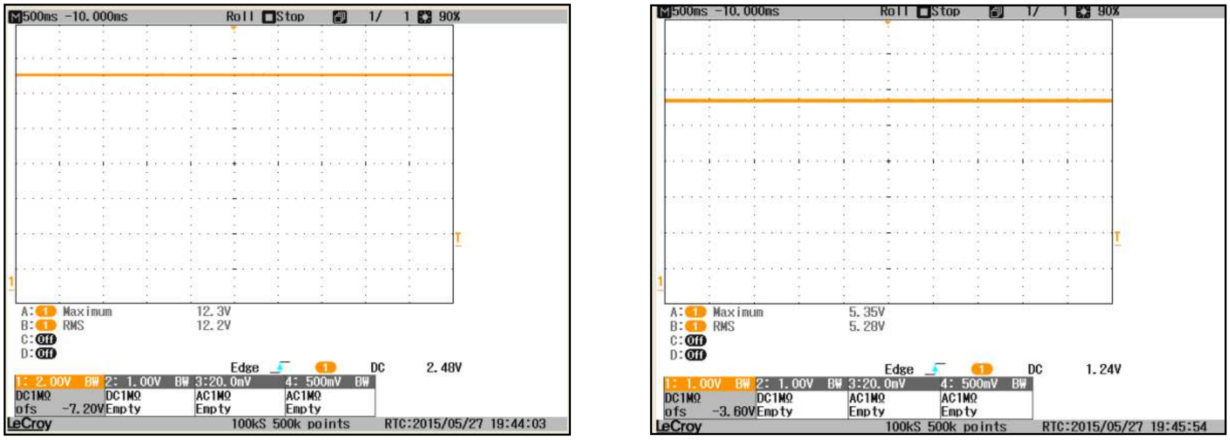
A time-based test shown in Figure 7B is conducted using a projector with a 200W rated power to evaluate the standby power consumption over 6 hours. The results show a consistent reduction in standby power with the design, with an average improvement of 99.35% compared to the unit without the design.

RESULTS AND DISCUSSION

The implementation of the zero standby power circuit using a Fixed-Frequency Flyback Converter, current sensor, and PIR sensor was aimed at minimizing standby power consumption and improving efficiency. This section summarizes the key findings, presents the descriptive statistics, and discusses the implications of these results.

a. Prototype Circuit Performance

The output regulation tests for +12V and +5V at a 30mA load showed regulation percentages of 1.67% shown in Figure 8A and 5% shown in Figure 8B, respectively. These values indicate efficient voltage regulation under the given load, meeting the expected performance criteria. Additionally, the burst mode operation at standby showed a compensation frequency of 100 kHz, significantly reducing frequency losses.

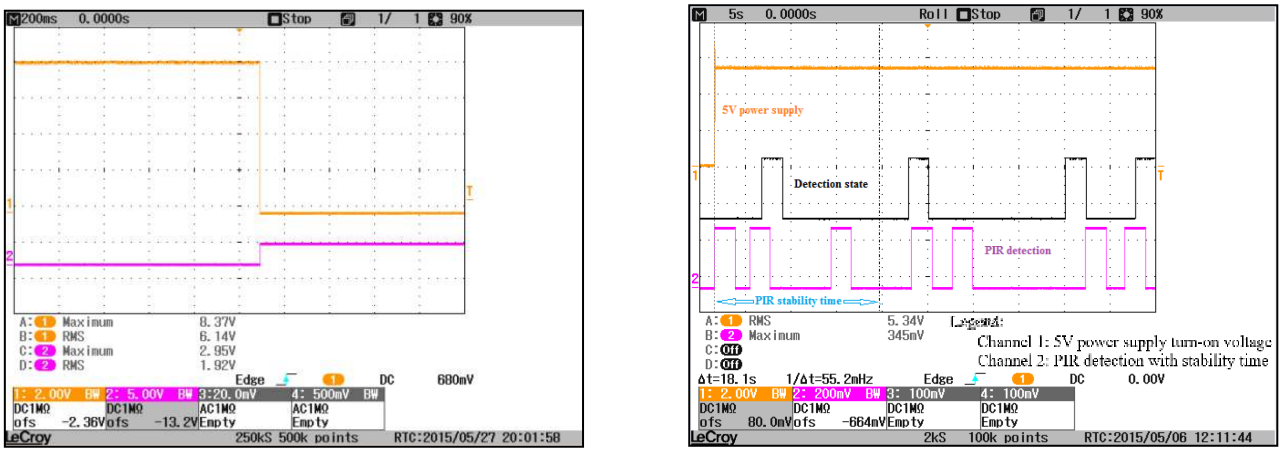


(A) (B)

Figure 8. **Voltage output regulation at 30mA load of the Flyback Converter (A) +12V (B) +5V**

Source: Author

The PIR sensor circuit achieved a Vgs voltage of 8.14 Vrms as shown in Figure 9A, with an accuracy rate of 98.25%, suggesting minimal variance from the theoretical values. The stability time for the sensor was 18.1 seconds as shown in Figure 9B, with an output of 3.45V, demonstrating the reliable response time of the sensor.

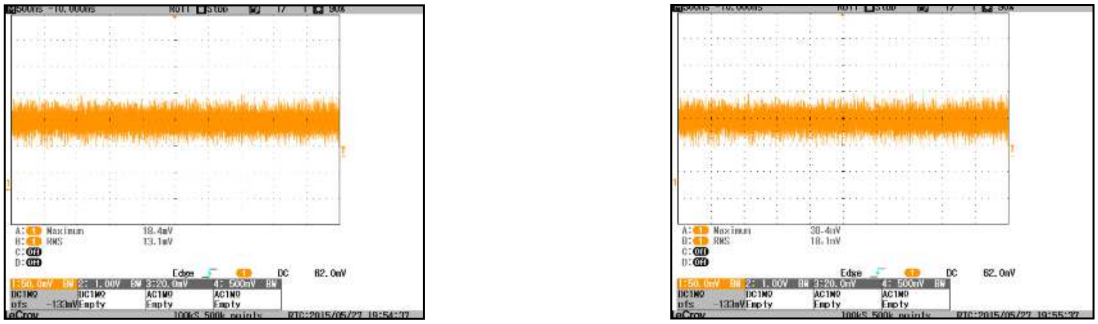


(A) (B)

Figure 9. **PIR sensor (A) Vgs voltage on Q3 MOSFET using actual prototype (B) Digital Output during stability duration**

Source: Author

The current transformer was evaluated in both standby and operational modes. In standby mode in Figure 10A, the output was measured at 13.1 mVrms, showing 93.8% accuracy, while in operational mode in Figure 10B, the output increased to 18.1 mVrms, with a 97.12% accuracy. These results confirm that the current transformer performs effectively in detecting changes between the two states.



(A) (B)

Figure 10. **Current Transformer Processing circuit output actual measurements w/ 1.5KW load during (A) standby state (B) work-mode**

Source: Author

b. Standby Power Reduction and Efficiency

Implementing the zero-standby circuit reduced standby power consumption from 5.08W to 0.07W, a 98% reduction, demonstrating its effectiveness in minimizing power wastage. Efficiency measurements under standby mode averaged 88.41%, surpassing the typical 80% benchmark, further validating the circuit's ability to maintain high efficiency even at low power levels.

Discussion

The results demonstrate that the zero-standby power circuit effectively meets the research objectives by significantly reducing standby power consumption and maintaining high efficiency, confirming its potential to minimize energy wastage. With 98.25% accuracy in the PIR sensor and strong current transformer performance, the circuit is well-suited for devices requiring low standby power and efficient energy management. However, a higher-than-expected variance (5%) in +5V output regulation suggests room for improvement in power supply design. Future work should focus on optimizing voltage regulation and applying the design to higher-power devices.

CONCLUSION

In the design and implementation of a zero-standby power system using a fixed-frequency flyback converter, the researcher has the following conclusions:

- The fixed-frequency controller for the flyback converter was successfully designed and integrated, achieving the goal of zero standby power consumption.
- The system, comprising the flyback converter, current sensor, and passive infrared (PIR) sensor, demonstrated effective performance in eliminating standby power.

- A printed circuit board (PCB) prototype was developed and tested, showing reliable operation at both low (85 Vrms) and high (265 Vrms) line voltages.

Simetrix simulations and experimental tests confirmed standby power consumption of 70-90 mW, meeting the 80 Plus standard with 80-95% efficiency at a 1.5 kW load. This shows potential for improving energy efficiency and scalability across consumer electronics. However, PIR sensor accuracy and efficiency variations need improvement. Future work should focus on enhancing sensor performance and optimizing control algorithms to further reduce energy consumption.

RECOMMENDATIONS

1. **Implement a Standard Layout:** Adopt a standardized layout for the fixed-frequency flyback converter to minimize signal distortion and reduce interference in the control circuits.
2. **Optimize Low-Power Components:** Utilize optimized, low-power components to further decrease overall power consumption, enhancing the efficiency of the system.
3. **Prioritize Cost, Safety, and QA Standards:** Ensure that the design adheres to cost-effectiveness, safety regulations, and Quality Assurance (QA) standards to improve the reliability and scalability of the zero standby power system.

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