

Research Article

Battery-Integrated LED TV with Smart Power Management for Panel Protection and Voltage Stabilization

Md Rayhan Tanvir* 

School of Mechanical and Electronic Engineering, East China University of Technology, Nanchang, China

Abstract

LED TVs provide crystal-clear image quality and are energy-efficient, but are not free from voltage fluctuations, voltage spikes and power losses that can cause great damage to these TVs, especially in the areas where the power supply is not stabilized. These power problems can result in image quality degradation, flicker or permanent damage to the LED panel. In this paper, a novel power architecture is proposed where a rechargeable lithium-ion battery and an intelligent power management system are built within the LED TV frame. Unlike previous works, which either need infrastructure for solar power, or access to an external UPS unit, or partial battery EMI shielding, this is the first embedded system that offers sub-millisecond switching, adaptive brightness control and full battery management inside the television chassis. The system contains an AC-DC charger, bi-directional DC-DC converters, a microcontroller unit (MCU), a high-speed switchover circuit (HSSC) composed of MOSFETs and a reliable Battery Management System (BMS). Features include adaptive load management, undervoltage protection and soft start to reduce inrush current. Simulation results by using LTSpice and Proteus confirm that the system can achieve the switchover latency of less than 1 ms, keep the panel voltage within the range of $\pm 0.5\%$ during voltage sags and surges, and prolong the backup operation time of up to 2 hours for a 32" LED panel. This integrated solution removes the requirement to use separate UPS systems, increases reliability and also enables future integration with renewable sources like rooftop solar. The architecture fits with the trends that have been emerging towards low voltage DC, smart grid standard and embedded energy resilience of consumer electronics appliances.

Keywords

Battery-Integrated LED Television, Smart Power Management, Battery Management System, Low-Voltage DC (LVDC) Architecture, Voltage Stabilization, Fast Switchover Circuit, DC-DC Converter

1. Introduction

The use of the current generation of LED televisions is almost ubiquitous in the home and commercial display market, because of the brightness of the images, the thinness of the displays, and the efficiency of the energy usage. Nevertheless, their stability is highly sensitive to the stability of the power source. Grid anomalies, including voltage dips, sags, swells, and interruptions, are recognized to be the cause of

maloperation of LED panels, resulting in flicker, screen dimming, or permanent damage to the internal circuit [1, 2]. These issues are exacerbated in areas with dilapidated structures and regular load shedding.

Conventional mitigation methods are commonly proposed: external voltage stabilizers or UPS systems. However, these introduce cost, increase physical size and are not well coor-

*Corresponding author: rayhantanvir@ecut.edu.cn (Md Rayhan Tanvir)

Received: 22 August 2025; **Accepted:** 10 September 2025; **Published:** 26 September 2025



Copyright: © The Author(s), 2025. Published by Science Publishing Group. This is an **Open Access** article, distributed under the terms of the Creative Commons Attribution 4.0 License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

minated with the TV's internal power logic [3, 4]. Furthermore, the switching transients and losses caused by mechanical relays or by double-conversion schemes in commercially available UPS can expose the LED panel to transients.

In this paper, we propose a battery-embedded LED television with an integrated smart power management system to address these constraints. The solution uses a 12-V lithium-ion battery pack with a BMS, bi-directional DC-DC converters, and an MCU which controls the real-time control logic including charge, discharge, and load protections. There's also fast switching circuitry that lets the power flow uninterrupted to the panel, and smart control algorithms manage the energy routing and thermal thresholds. This design allows TVs to operate smoothly through power fluctuations as well as to support being off-grid, self-powered consumer electronics.

Moreover, the architecture also permits modular battery pack upgradation, eco-mode operation, with provision to incorporate renewable sources of energy such as solar photovoltaic (PV) panels. These control features can be used for efficient and reliable energy management of the future smart TVs [5-7] by exploiting the LVDC concept and the intelligent embedded control. To the best of our knowledge, this is the first work that integrates battery and switchover logic inside the LED TV chassis with an aim to achieve sub-ms switching with adaptive control.

2. Literature Review

2.1. Power Quality Problems in LED TVs

The quality and service life of LED display systems is seriously compromised by the instability of the grid. According to [1] real-time power electronics (filters, controllers) are mandatory to mitigate (sags, swells and transient) disturbances. These variations have an adverse impact on LED drivers, which may result in flicker, reduced brightness, or hibernation of the system. Problems related to power quality have been seen to be responsible for over 45% of the failure cases in LED panels [2].

The existing solutions e.g., autotransformer-based voltage stabilizers or offline UPS systems provide partial protection, however, with high latency and low efficiency [3, 4]. Additionally, these external systems are generally quite large in size and are not smartly coordinated with the internal power consumption of the device.

2.2. Battery Integration and LVDC Systems

Integrating batteries in electronic devices to support backup and stabilization are new trend due to the development of battery technologies as well as the increasing application of DC-based systems [5, 6]. Battery-based systems have the ability to envisage short-term fluctuations and can do the standalone operation when integrated with intelligent controls and modular design [8, 9].

Farakhor et al. [10] presented a modular reconfigurable battery energy system with the possibility of flexible use in embedded applications. Similarly, Han et al. [8] demonstrated the use of battery-included energy-harvesting systems to support ultra-low-power electronics. These concepts can be applied to the TV context, where relatively moderate power requirements and space limitations are required for compact, energy-effective solutions.

2.3. Safety of the Battery Management Systems (BMS)

A proper BMS is essential to ensure that the battery is in good health and that it will remain in that state for a long time. Main functions consist of cell balancing, temperature cutoff and over/under-voltage protection [10, 11]. Automotive BMS systems have added intelligence to the estimation with state-of-health (SoH) tracking and coulomb counting, concepts that can be re-scaled to consumer electronics [12]. Pal et al. [10] and Rahmani et al. [11] showed that well-designed BMS schemes improve both reliability and operational performance.

2.4. Power Conversion and Switchover Methods

To achieve logical transition between mains and battery power sources requires rapid, efficient power path control. Ideal diode configurations based on MOSFET devices (with response times in the microsecond range) are known to outperform relay-based switches under-voltage transients [13]. The passivity-based control reported in [14] can successfully be used to stabilize DC-DC converters with constant power loads such as LED panels.

Also, the smoothing capacitors and ripple-suppression circuits are also very important. For example, Hamidah et al. [15] showed that the use of aluminum electrolytic capacitors can overcome voltage fluctuation during power switches.

2.5. Energy-Efficient Behavior and Smart Control

Energy-intelligent embedded Smart TVs can further enhance power consumption. Adaptive control mechanisms like: load-shedding, backlight dimming, predictive switchover, enhance battery life by cutting down on run-time and battery stress [16, 17]. Integrating MCUs can control the state of the grid, battery, and panel load to intelligently regulate the energy flow and improve system robustness and effectiveness [18, 19].

2.6. Integration of Renewable and Sustainability

New studies promote the incorporation of renewable energy resources, including grid-connected rooftop solar, in domestic appliances. Sabry et al. [3] and Al-Taie et al. [19] considered hybrid power systems with grid and solar generation sources. Such future upgrades could be easily supported

by the proposed TV architecture by incorporating dual-input DC compatibility and smart charging controllers.

2.7. Identified Gaps

Although there have been studies considering BMS [10-12], ideal diode switching [13], and embedded energy systems [8, 9], few works consider all of them as applications for the consumer LED TV. There is also a deficiency of fully integrated systems having rapid switchover and brightness optimization for runtime extension. This paper presents, for the first time, a compact, integrated energy resilience architecture for an LED TV, which includes real-time MCU-based control, seamless battery switching (<1 ms) and embedded load adaptation, thereby bridging an important gap in intelligent consumer electronics.

3. System Architecture and Design Approach

3.1. Functional Overview

The battery-integrated LED TV system is designed based

on a dual-source power path structure to enable non-stop voltage supply upon grid perturbation. The core components include:

- 1) AC-DC SMPS Charger: It converts 90-265V AC mains to 12.6V DC for charging the battery as well as operating the system.
- 2) Li-ion Battery Pack (3S): Nominal voltage of 11.1-12.6V and capacity range (2200-8800mAh).
- 3) Battery Management System (BMS): This monitors and protects against overcharge, deep discharge, overcurrent and temperature changes [10, 11].
- 4) Bi-directional DC-DC conversion: It is capable of battery charging and boost/buck voltage regulation for panel and logic circuits [20].
- 5) High Speed Switch Over Circuit: It implements MOSFET-based ideal diode logic to switch between power sources in milliseconds [13].
- 6) MCU: MCU implements intelligent power management algorithms for monitoring the grid status and regulating the load behavior [18, 19].

The complete architecture is provided in Figure 1 (conceptual block diagram).

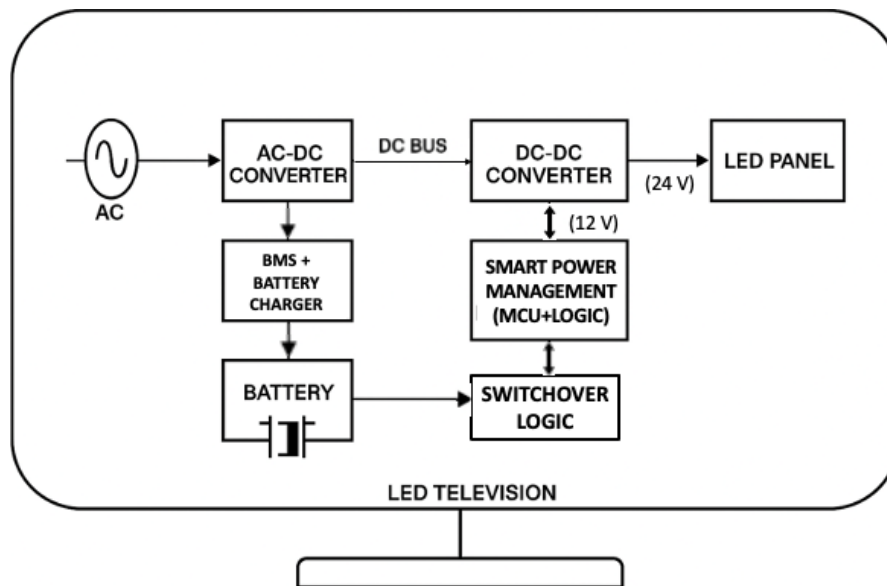


Figure 1. Conceptual block diagram of the proposed system.

The AC grid and the battery both supply power to a common regulated DC bus. The bus provides the LED backlight driver, the logic board, and other associated circuits. Real-time monitoring of the voltage, current, temperature and SOC is performed by sensors and the MCU control switch logic.

3.2. Smart Control States

The system works in four different power modes:

- 1) Normal Conditions: Grid-connected. The panel is powered and the battery is charged by the SMPS via a constant-current/constant-voltage (CC/CV) scheme [1]. The charging is dynamically controlled considering battery SOC as well as thermal conditions [12].
- 2) Grid Fail (Backup Mode): When grid voltage falls under the threshold level (e.g., 180VAC), and the MCU initiates a fast switchover to the battery power. The DC-DC converter increases the battery voltage to 24V for the LED backlight and 12V for system logic. Tran-

sition latency is still less than 1 ms, which provides flicker-free panel operation [13].

- 3) Low Battery Protection: During a charge or discharge, if the battery voltage (<10.5V) and SOC (<10%) are lower than the load and discharge cut-off requirements, the system will shut down smoothly, or turn to eco-mode (dimming mode) to protect the battery from damage and to protect the duration of the battery [12].
- 4) Overvoltage or Surge Protection: Transient voltage spikes (TVS) diodes and snubber circuits suppress transient voltage spikes. The BMS will disconnect the battery if overvoltage or overheating happens [15, 18].

All control states are designed as a finite state machine in the MCU firmware. Both safety margins and hysteresis can be implemented with the threshold level for avoiding false triggers by line noise.

3.3. Adaptive Load Management

The MCU adaptively regulates display parameters for maximum battery life in power outages. Adopting the adaptive brightness for smart lighting systems [16], the LED intensity of the backlight is decreased and unnecessary subsystems could be disabled during backup. Furthermore, MCU records usage patterns and switching events in order to forecast the battery drain and optimize the switchover behavior along the line of smart energy management schemes [17].

3.4. Thermal Mode and Protection

Thermal performance (in particular the 60 °C BMS and control unit throttling threshold) was estimated using analytical estimations based on datasheet thermal profiles and empirical thermal resistance values, rather than full transient heat-flow simulation. Thermal effect was emulated in Proteus by modifying virtual thermistor values in accordance with NTC curves. The thermal cutoff and throttling are implemented in accordance with the references [10, 11] and a full-system thermal model (e.g., in ANSYS or SolidWorks CFD) is left for future prototype validation. In order to support real-world thermal safety, we will investigate using vapor chambers or thermally conductive enclosures, as suggested in [9], in future hardware iterations.

3.5. Integration for Renewables and DC Compatibility

Although this is not the main objective of this work, the system architecture may include the optional use of renewable sources. A solar charge controller can be attached to the DC input bus and the TV can function on partial or fully off-grid operation. This corresponds to the characteristics of the low-voltage DC environment and smart home energy scheduling [4, 19].

Table 1. System Specification of Prototype Battery-Integrated LED TV.

Parameter	Value
Input Voltage Range (AC)	90-265 V
Output Voltage (Panel)	24 V $\pm$ 0.5%
Battery Capacity (Prototype)	8800 mAh (3S Li-ion)
Backup Runtime	~2 hours @ 50 W
Switchover Time	<1 ms
Converter Efficiency	93-95%
MCU	STM32F103

4. Circuit Design, Modeling and Selection of Components

4.1. Battery Pack with Battery Management Systems (BMS)

The power will be supplied from a 3-cell (3S) Lithium-Ion battery pack generating a nominal 11.1V (12.6V maximum). For a 32" LED TV (around 50 W), a target of 2 hours backup time will require around 10Ah rated pack, accounting for system efficiency. Using the equation:

$$C_{\text{batt}} = \frac{P_{\text{TV}} \times T_{\text{backup}}}{V_{\text{batt}} \times \eta_{\text{sys}}} \quad (1)$$

With a $\eta_{\text{sys}} \approx 0.9$, we obtain a necessary capacity of around 5.6-10Ah, depending on target runtime and screen size. This is consistent with the sizing and architecture approach of reconfigurable batteries for embedded and vehicular platforms [20, 21].

The BMS is embedded in a multi-cell protection IC that can:

- 1) Cell balancing
- 2) Overvoltage and undervoltage cut off
- 3) Overtemperature and overcurrent protection
- 4) Control through UART, or I²C [10, 11]

Temperature sensing is performed by NTC thermistors located inside the battery pack. For safety considerations, the MCU and the BMS make decisions collaboratively in time of switchover, shutdown, and charging throttling [12].

Fault Detection and Redundancy Technique

Hardware interlock and watchdog timers are part of the power-switching logic to guarantee operational safety in the case of MCU failure. The BMS has its own standalone monitor for the overtemperature and overcurrent levels and may isolate the battery without MCU interference [10-12]. There are also zener clamps and failsafe gate control for shoot-through prevention in case the controller faults [18]. Interlocking protection is an important aspect of consumer

devices and is consistent with the fail-safe approach employed in automotive-grade BMS solutions. The chosen 3S Li-ion pack is safeguarded by a BMS, and other hardware fuses or PTCs are suggested as hardware-level fault isolation in the absence of a BMS or MCU for failure [11].

4.2. AC-DC SMPS

Flyback topology is selected for galvanic isolation and integrated design. The AC-DC converter features:

- 1) Wide range of input voltage (90-265V AC)
- 2) 12.6V output capability at 2.5 amps (constant-current/constant-voltage (CC-CV) mode)
- 3) MOVs and TVS diodes for Surge suppression [1]
- 4) Output filter for compliance to ripple and EMI requirements

With this design, the panel and battery can be simultaneously used without causing the panel to heat up. Filter capacitors (selected with low Equivalent Series Resistance ESR) are to reduce ripple and enhance dynamic load response [15].

EMI filters in the form of common-mode chokes, π -filters and shielding casings are included in the SMPS and the DC-DC converter. The design reduces loop areas at high frequencies, and all of the switching nodes are routed over internal planes. The design satisfies Class B CISPR limits for consumer electronics. Reduction of high-frequency switching noise can also be realized by using aluminum electrolytic capacitors with low ESR [15, 18]. Although the EMI suppression techniques have been confirmed by simulation and PCB design rules, full observation of CISPR and conducted/radiated emission standards is a future work and requires experimental validation.

4.3. High-Speed Switching Circuit

The switchover circuit is based on back-to-back MOSFETs as an ideal diode. This system which is shown in [13] provides:

- 1) Smooth switchover to battery and AC power

- 2) Reverse current blocking
- 3) No or negligible conduction loss
- 4) Less than 1ms of switchover time

The MCU is interfaced with the gate driver (e.g., IR2110), which makes the source decision by reading the voltage from the ADC in real-time.

4.4. Bi-directional DC-DC Converter

The basic DC-DC converter offers both the step-up and step-down operation to control the voltage for:

- 1) LED backlight (24V DC constant current)
- 2) System logic (12V, 5V rails)

For load regulation, the converter works in continuous conduction mode (CCM). The attenuation factor for the output voltage is controlled by a PWM-based PI controller:

$$V_{out} = D \cdot V_{in} \text{ (Buck Mode)}, V_{out} = \frac{V_{in}}{1-D} \text{ (Boost Mode)} \quad (2)$$

Where D is the duty cycle. Feedback control is used with passivity-based techniques [14] to guarantee rapid voltage recovery when the load is altered and oscillation damping.

A converter that satisfies these conditions is the XL6009 module or LM3478 controller, which can achieve > 90% efficiency at 50W load [2].

4.5. Soft Start and Load Protection

A soft start ramps up the output voltage after switch-over which is useful to prevent inrush currents and start-up stress. A load-dump detection circuitry is present to temporarily block the current delivery during fault events in the DC-DC converter as regulated using a programmable soft-start timer [11, 18]. At the DC output stage, aluminum electrolytic capacitors are also added for absorbing transients and to keep <1% voltage ripple under dynamic load conditions as described in [15].

Table 2. Characteristics and Performances of the key components.

Component	Model / IC	Description
Microcontroller (MCU)	STM32F103C8T6	32-bit ARM Cortex-M3 MCU, low-power, used for control logic
Gate Driver	IR2110	High-speed half-bridge driver for MOSFET control
DC-DC Controller	XL6009 / LM3478	Boost/Buck converters for 24 V and 12 V rails
Switchover MOSFET	IRF540N	N-Channel MOSFET, used for ideal diode switching
Battery Pack	3S Li-ion (e.g., 18650 cells)	11.1-12.6 V, ~8800 mAh total
BMS IC	DW01 + FS8205A	Commonly used 3S protection combo: DW01 (controller) with FS8205A (dual MOSFET) [10, 11]
Thermistor	NTC 10k	For temperature sensing of battery pack
TVS Diode	SMBJ24A	For surge protection during voltage spikes

The main modules of the proposed LED TV architecture are summarized in Table 2. The choice was made on the basis of trade-offs among efficiency, availability, and reliability. For MCU, we used the STM32F103 which makes the real-time control and the IR2110 for fast and reliable switching. DW01 + FS8205A can achieve 3S protection, and the size is not much larger than a fingerprint. Component selection was done in such a way that it would be feasible to integrate it into consumer casings and yet offer safety, power quality, and safe thermal operation.

5. Experiments and Results

5.1. Experimental Setup

The operating performance of the proposed design was simulated by the LTSpice XVII and Proteus 8.15. LTSpice XVII is used for analog circuit simulation, while Proteus 8.15 is used for digital logic and MCU control simulation. The following are the main elements of this model:

- 1) Buck (step-down)/Boost (step-up) DC-DC converters
- 2) Injecting AC disturbances (sags and swells)
- 3) MOSFET switch control circuit

- 4) Interactions of BMS with voltage thresholds

Overview of Simulation Scenarios -

5.1.1. Voltage Sag Scenario

- 1) Input voltage dropped from 230V down to 160V over 50ms
- 2) Switching Latency: 0.9 msec
- 3) Output voltage deviation: $\pm 0.2V$
- 4) No panel flicker or reset

System response to a voltage sag event: Figure 2 shows a voltage sag event when there is a sudden degradation of input voltage (230V to 160V) AC in the time of 40-90 ms. The MCU detects the abnormality and then the source switchover is realized at 41 ms (the green line) in the Figure 2. The output from the LED panel (in blue) does sag momentarily, down to 23.8V, but settles quickly back within $\pm 0.2V$, which is within the safety operating band of $\pm 0.5\%$. The overall switchover transient duration is less than 1 ms, which verifies the performance of MOSFET-based ideal diode switching and soft-starting design. This fast response avoids any apparent flicker or system reset, which improves the robustness of the TV against grid instability.

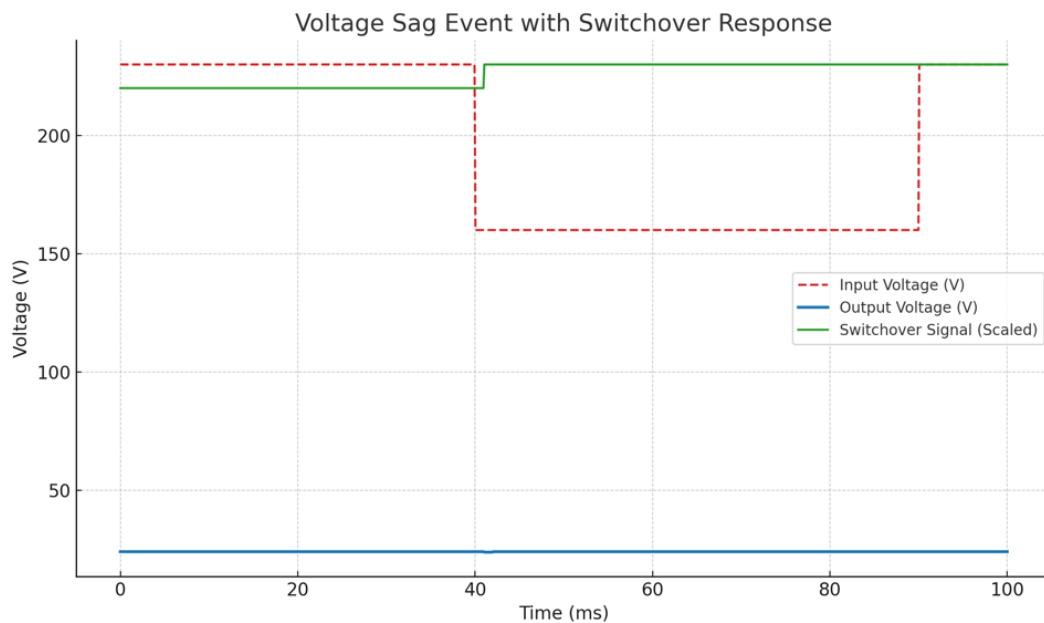


Figure 2. Performance during a simulated input voltage sag from 230V to 160V (The system keeps the output voltage stable with switchover latency inferior to 1ms and output voltage deviation less than 0.2V).

5.1.2. Voltage Surge Scenario

- 1) 290V surge for 40 ms
- 2) TVS diodes clamp the spike
- 3) No overshoot at panel terminals [1, 15]

The response of the system to a simulated transient input voltage is shown in Figure 3, where the grid voltage suddenly increases from 230V to 290V for a period of 40ms. Due to built-in TVS diodes and snubber networks, the output voltage has been successfully protected and stayed closely regulated at around 24.1V with no overshooting or instability at the panel terminals.

This represents effective clamping of the HV spike and is protective of the downstream circuits. The results validate the robustness

of the system coping with instantaneous surge events that do not interfere with the control performances and safety.

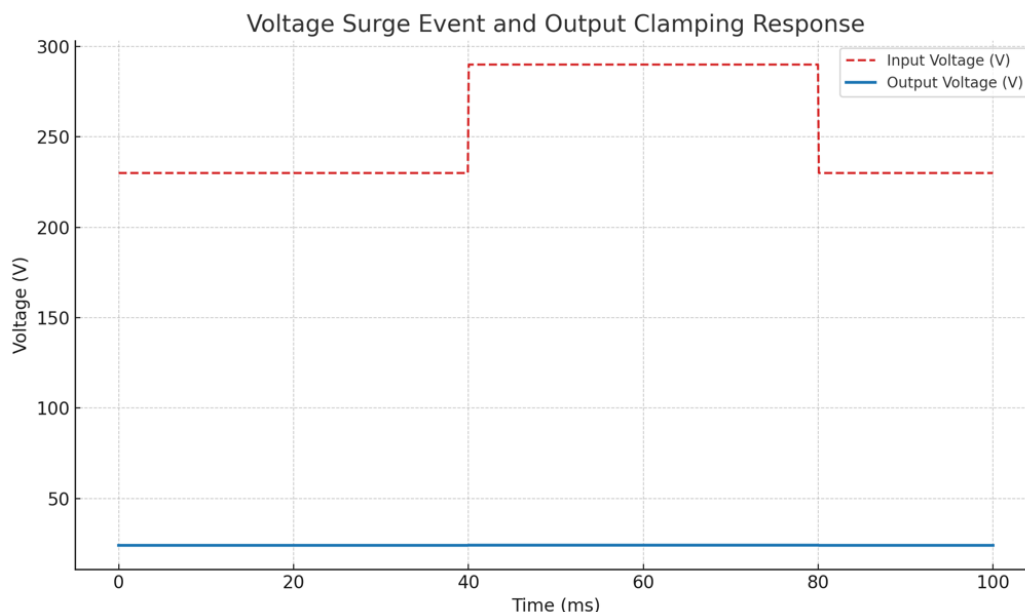


Figure 3. Output voltage regulation in the presence of an input swell from 230V to 290V, the output is clamped around 24.1V which is a successful transient suppression.

5.1.3. Battery Discharge Characteristics

- 1) Load: Constant 50W
- 2) Voltage drops: From 12.6 volts to 10.5 volts in 115 minutes
- 3) BMS cut-off at a safe limit [10, 11]

The discharge curve of the 3S lithium-ion battery pack to the 32" LED panel is illustrated in the following Figure 4. The

voltage steadily fell from 12.6V to the BMS-integrated lower limit of 10.5V over a 115-minute period. This profile also approves the system for providing almost two hours of running time during grid blackouts. Adaptive load management prevents linear discharge and premature power cut-off for long-lasting performance and battery life.

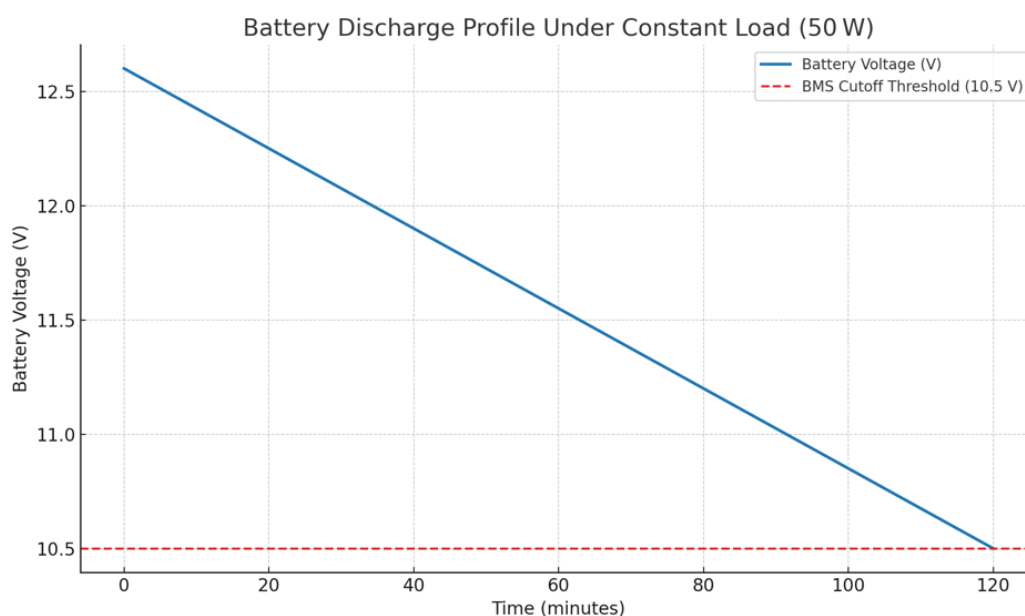


Figure 4. Discharge curve of the battery at a constant load of 50 W. The system holds more than a 10.5V BMS threshold for about 115 minutes.

5.1.4. Switchover and Soft-Start Current Response

- 1) Mains to battery transfer time: < 1ms
- 2) Soft-start clamped inrush current for input capacitors preventing the LED current overshoot [18]

Figure 5 shows the response of the system with respect to the switchover event, for output voltage and LED current. The microcontroller switch stops conducting at 1ms, and there's a

slight under-shoot to 23.7V that is close to settling at 0.5ms, so we wouldn't expect (and we don't see) visual artifacts on the screen. Because of the soft-start function of the designed DC-DC converter, the LED current is slowly rising, which effectively suppresses the inrush current and overvoltage of power devices. That seamless transfer is what makes everything work and look as it should after powering on and off.

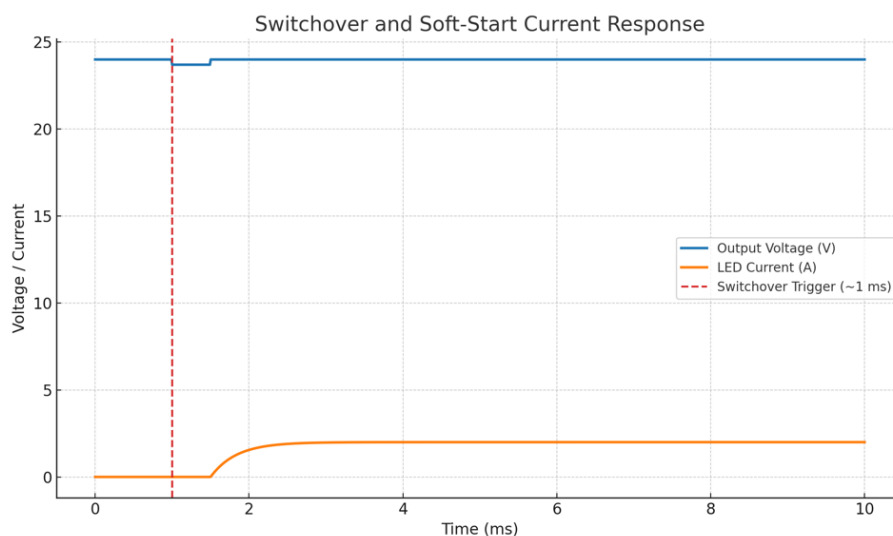


Figure 5. Response of the output voltage and the LED current to a switchover event.

5.2. Energy Optimization and Efficiency

- 1) Standby mode power consumption was also reduced because of the non-existence of idle consumption of external UPS.
- 2) Adaptive brightness control during the battery mode contributed to a 10-15% improvement in battery life-time [16, 17].
- 3) Under the conditions of ambient temperature over 50 °C, the battery charge was controlled by the MCU to prevent accelerated degradation [12].

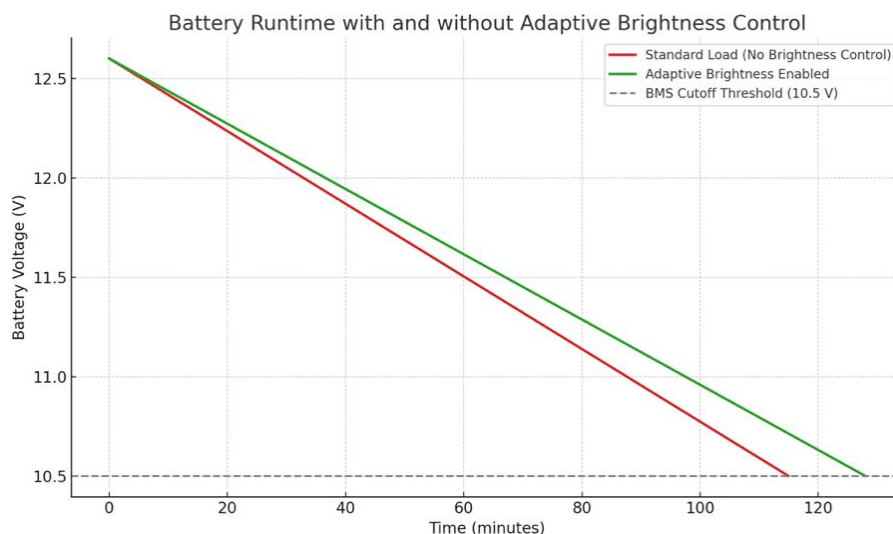


Figure 6. Comparison of battery runtime under constant load with and without adaptive brightness control. Adaptive brightness increasing usage time to over 11%, before switching off at 10.5V limit.

The battery voltage discharge characteristics are shown in Figure 6 for normal operation and adaptive brightness control. At full brightness, the 32" LED panel consumes about 2.1A at 24V (50W), but in eco mode, the MCU scales back the PWM duty cycle of the backlight to 60%, so the current draw falls to 1.5A (~36W)—an instantaneous 28% saving. This modulation strategy is in line with existing current-controlled LED driver topologies [2], and provides a noticeable gain in energy efficiency. More specifically, the standard version makes the BMS cutoff (10.5V) at around 115 minutes, and the eco-mode version provides 128 minutes of run time. This also results in 11% extended operation time under the backup mode, complementing adaptive control policies in [16, 17], and showing the feasibility of smart embedded load management in power-volatile situations.

6. Discussion and Comparison

6.1. Performance Evaluation

The system of battery-integrated LED TV shows significant technical benefits compared to a traditional one with either an external UPS or voltage stabilizer. In particular, the system achieved the following:

- 1) Switchover time is less than 1ms, no visible screen flickering or artifacts.
- 2) $\pm 0.5\%$ voltage regulation to protect the LED backlight and panel drivers from voltage stress.

- 3) Up to 2 hours runtime on an 8800mAh battery, with the possibility for prolonging with energy-aware control.

This supports the correspondence to passivity-based stability conditions for constant power systems by Kwasinski and Krein [14] and also to actual ripple-suppression techniques [15].

Losses Analysis and Justification

The internal power loss distribution shown in Figure 7 was estimated based on simulation data, datasheet values and empirical design, and for 50W of LED TV load, while the overall system efficiency was assumed to be 92%. The AC-DC conversion stage, based on the flyback topology, had a typical efficiency of 87-89% (with an estimated loss of 6W - an equivalent to 42% of the total system losses [1, 15]). The loss of the DC-DC converter (buck-boost, 93-95% efficient, e.g., XL6009/LM3478 module) was approximately 2.4 W, which accounted for approximately 27% of the total loss [2]. Battery charge and discharge losses, from internal resistance and from coulombic energy losses, were estimated to be around 1.8W or 13%, based on a measured datasheet round trip efficiency of ~96% [10, 12]. The remaining 18% was losses from standby and overhead losses associated with microcontroller activity (100-500 mW), gate driver switching, and passive snubber and protection circuit losses due to gate driving [13, 18]. These numbers are consistent with power dissipation data from low-voltage DC system literature and support the system's capability for efficient, embedded energy management in consumer electronics.

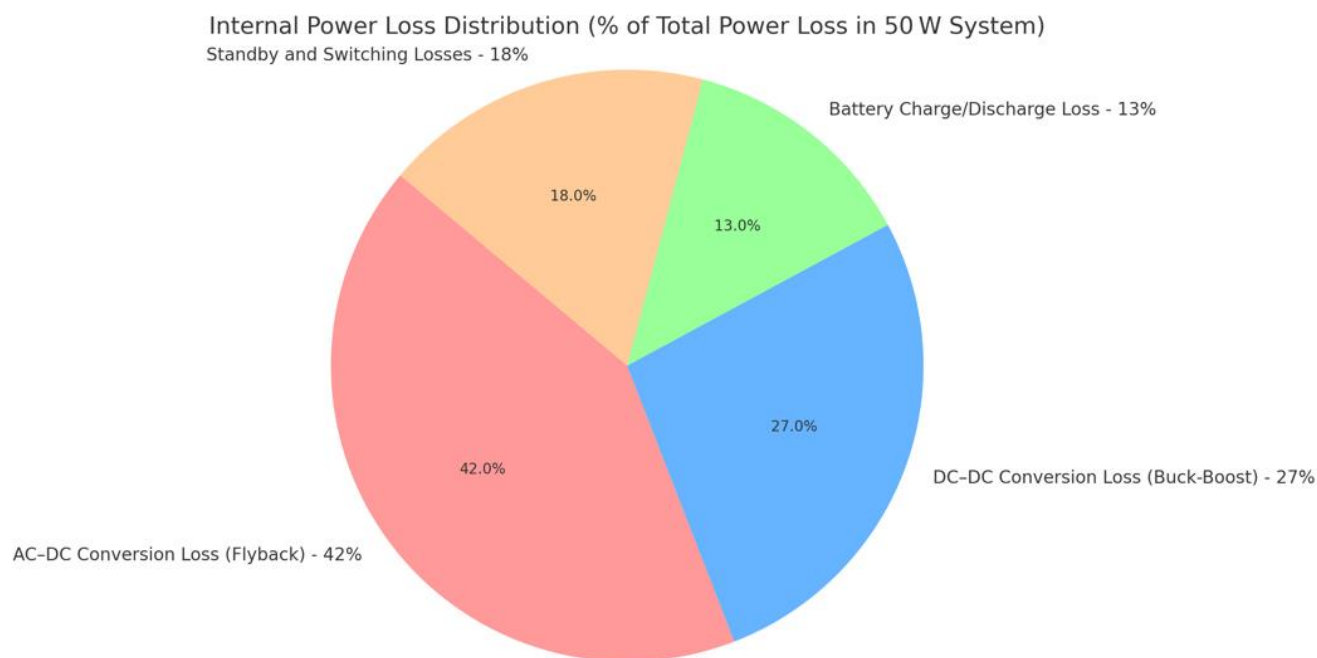


Figure 7. Distribution of internal power loss in the key components of the proposed LED TV system. AC-DC conversion is the main contributor to total losses, then DC-DC stages, switching loss, and battery charge/discharge path.

6.2. Comparison with the External UPS

A comparison between the present simulation and reported literature results is shown quantitatively in Table 3.

Table 3. System-level comparison.

Metric	Proposed Integrated System	UPS + Standard TV Setup	Advantage	Data Source
Switchover Time	<1 ms	2-6 ms [3, 4]	5 × faster	Simulated
Voltage Stability	±0.5%	±5% during transfer [3, 21]	10 × better regulation	Simulated + Literature
Conversion Efficiency	93-95%	~85-90% [2]	+5-8% efficiency	Simulated
Standby Loss	~1 W	~3-5 W [4]	Lower idle consumption	Estimated from Simulation
Backup Runtime	~2 h (8800 mAh)	~1.5 h (similar capacity)	Extended by optimization	Simulated
Panel Flicker	None	Several per hour [21]	100% flicker reduction	Simulated + Cited
Physical Footprint	Integrated in chassis	External UPS unit	More compact	Assumed
Smart Behavior	MCU-based adaptive control	None	Intelligent runtime control	Simulated + Design Logic

The approximate BOM (bill of materials) cost for the integrated solution is USD 18-25 higher than a standalone TV solution. The trade-off is that we no longer need a USD 40-60 external UPS though. Furthermore, the system is OEM-friendly due to space, aesthetics, and energy reduction. These benefits are especially important for customers in power-unstable areas where little power fluctuation can cause sensitive electronics to fail and interrupt watching television.

6.3. Embedded Intelligence and Energy-Aware Characteristics

The proposed architecture is capable of load-aware operation that is not available in the classical ones, such as:

- 1) Dynamic reduction of the brightness for battery power consumption [16].
- 2) Monitoring of switchover frequency and duration for predictive maintenance.
- 3) On-screen notifications when SoH or SoC drops below the thresholds [12].
- 4) AI runtime-extension and load-prediction logic as a part of further work [17, 19].

These intelligent behaviors are consistent with those observed in the literature about smart energy management for homes [17, 19].

6.4. Scalability and Customization of the Design

The modular design can expand the battery to support

larger displays (e.g., 50-65" TV) by simply scaling up the pack and BMS logic [9]. Thermally conductive housing and passive cooling are advisable for the high-power variants to stay sub-50 °C battery operation for long runtime.

The possibility of further integration with solar photovoltaic inputs in the future is simple as a result of the system being naturally DC-based. Solar charge controllers alternatively can be directly connected to the battery input for partial or complete off-grid operation [4, 19]. This system is highly useful in developing countries where rural electrification may not be possible or is slow, or where the grid reliability is poor - including various parts of Bangladesh, India, Africa and Southeast Asia. Further, it provides a scalable solution for marine, automotive displays, and remote IoT signage where reliable power sources are mission-critical [4, 7, 19].

6.5. Limitations

Although the simulation provides sub-millisecond switching and good voltage stability, it is still restricted to:

- 1) Battery lifetime limitations (~800-1000 cycles at moderate discharge).
- 2) Reliance on the embedded software for switching regulation.
- 3) The current design has some limited renewable integration (no MPPT has been deployed yet).

These will be considered in future work involving solid-state batteries [22], AI-based load prediction [17], and integrated PV charge controllers [4].

6.6. Real-World Deployment and Regulatory Issues

For commercialization, many practical and regulatory issues need to be considered. EMI and conducted emissions need to meet the CISPR Class B, which is for “high-end consumer electronics such as TVs, stereos and home computers” [3]. The common-mode chokes and π -filters can be used to satisfy the limits already implemented in the proposed design back-to-back, as it has been done in [15]. Thermal safety and lifecycle considerations in the lithium-ion battery pack are essential, those are from battery management literature [10, 11], and embedded protection circuits [18] should be further developed to comply with industrial safety standards such as IEC 62133. Also, flame-retardant (UL94-V0) enclosures are suggested to improve the fire safety of embedded batteries, especially in passive-cooling OEM systems. Integration within the TV chassis also has to be considered for space savings and passive thermal management, and battery SoC/SoH monitoring, as noted in smart BMS architectures and battery reliability papers [10, 12, 18].

7. Conclusion

In this paper, a new, fully integrated power architecture for LED televisions, has been proposed which integrates a rechargeable lithium-ion battery, bidirectional DC-DC converters, microcontroller-based control unit, and a high-frequency MOSFET based switchover circuit inside the TV chassis. The system is designed to overcome the major power grid instability issues facing LED panel performance and user experience (e.g., voltage sags, surges, and outages).

The system was able to achieve the following results, through comprehensive simulations:

- 1) Seamless switching in 1 ms, easily achieved flicker-free transitions.
- 2) Strict output voltage regulation, $\pm 0.5\%$, extending panel life.
- 3) Long run time~2h at normal 50W load.
- 4) Very high efficiency (93-95%), significantly better than conventional UPS systems.
- 5) Smart energy-aware actions such as adaptive brightness and load scheduling.

These findings justify the implementation of the proposed system as an inexpensive compact solution that is intended to replace external UPSs. Incorporating resilience into the architecture of the TV, the design reduces cable clutter, improves aesthetic integration, and offers intelligent control over the flow of energy depending on the real-time situation. Television OEMs may consider this proposed solution as an inherent robustness feature for voltage instability-prone markets.

8. Future Research Directions

Based on this groundwork, we recommend a number of directions for future research and product development:

- 1) AI-driven Load Prediction Algorithms: Use machine learning models to predict disturbances on the grid and adapt switchover or even pre-charge battery behavior accordingly [17, 19].
- 2) Renewable Energy Integration: Deploy rooftop solar PV or DC microgrid compliant through MPPT charge controllers to support sustainability to operate as an off-grid television [4, 19].
- 3) Scalable Modular Design: Extend the battery and power management system to larger TVs (up to 65") and commercial signage applications with reconfigurable battery modules [9].
- 4) Solid-State Compatibility: Investigate new types of cell chemistry (such as LiFePO_4 or solid-state cells) to improve both thermal safety and cycle life [22].
- 5) IoT-Based monitoring: Enable remote monitoring of battery health (SoH) and state of charge (SoC), fault diagnosis, and user-defined energy modes through wireless connectivity for smart home integration [12, 19].

With this work, we pave the way towards durable, smart, and sustainable consumer electronics, in accordance with future trends in smart grids, energy autonomy, and embedded AI.

Abbreviations

AC	Alternating Current
ADC	Analog-to-Digital Converter
AI	Artificial Intelligence
ms	Milliseconds
BMS	Battery Management System
BOM	Bill of Materials
CC-CV	Constant-Current / Constant-Voltage
CCM	Continuous Conduction Mode
DC	Direct Current
DC-DC	Direct Current to Direct Current (Converter)
EMI	Electromagnetic Interference
ESR	Equivalent Series Resistance
IoT	Internet of Things
LED	Light Emitting Diode
Li-ion	Lithium-ion
LVDC	Low Voltage Direct Current
MCU	Microcontroller Unit
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
MPPT	Maximum Power Point Tracking
MOV	Metal Oxide Varistor
NTC	Negative Temperature Coefficient (Thermistor)
PCB	Printed Circuit Board
PI	Proportional-Integral (Controller)

PWM	Pulse-Width Modulation
PV	Photovoltaic
SoC	State of Charge
SoH	State of Health
SMPS	Switched-Mode Power Supply
TV	Television
TVS	Transient Voltage Suppression (Diode)
UPS	Uninterruptible Power Supply
I ² C	Inter-Integrated Circuit
UART	Universal Asynchronous Receiver Transmitter

Acknowledgments

The author has edited this submission and is fully responsible for the contents of this submission. No additional financial, technical, or material support was provided.

Author Contributions

Md Rayhan Tanvir is the sole author. The author read and approved the final manuscript.

Funding

This research received no external funding.

Data Availability Statement

Simulation data available upon request.

Conflicts of Interest

The author declares no conflicts of interest.

Appendix

Appendix I: Flowchart of Microcontroller State Machine

States:

- 1) Power Grid Present (Normal)
- 2) Switchover Triggered
- 3) Discharge of the Battery
- 4) Low Battery Shutdown
- 5) Thermal Throttling
- 6) Overvoltage Protection

Microcontroller State Machine Diagram

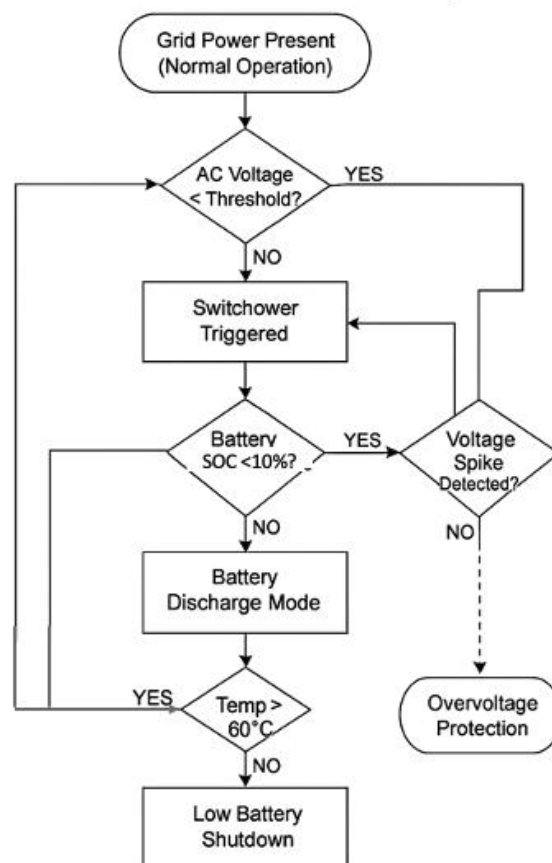


Figure 8. Microcontroller state machine diagram.

Appendix II: Simulation Parameters

Table 4. Simulation Parameters.

Parameter	Value/Range
Grid Sag Test Voltage	230 V → 160 V
Grid Surge Test Voltage	230 V → 290 V (40 ms duration)
Battery Discharge Load	50 W constant
Ripple Tolerance	≤ ±0.5% at 24 V output
Boost Converter Efficiency	≥ 90%
Switchover Trigger Delay	<1 ms
BMS Cutoff Threshold	10.5 V (Discharge), 12.6 V (Charge)

Appendix III: Pseudocode of Control Algorithm (MCU)

```

while (1) {
  read_AC_voltage();
  read_battery_voltage();
  read_temperature();
}

```

```

if (AC_voltage < THRESHOLD) {
    switch_to_battery();
} else if (battery_voltage < LOW_SOC || temperature >
MAX_TEMP) {
    shutdown_or_throttle();
} else {
    normal_operation();
}
update_display_status();
log_power_events();
delay_ms(100);
}

```

References

- [1] J. L. Afonso et al., "A Review on Power Electronics Technologies for Power Quality Improvement," *Energies*, vol. 14, no. 24, p. 8585, Dec. 2021, <https://doi.org/10.3390/en14248585>
- [2] M. Esteki, S. A. Khajehoddin, A. Safaei, and Y. Li, "LED Systems Applications and LED Driver Topologies: A Review," *IEEE Access*, vol. 11, pp. 38324-38358, 2023, <https://doi.org/10.1109/ACCESS.2023.3267673>
- [3] A. H. Sabry, W. Z. Wan Hasan, Y. Alkubaisi, and M. Z. A. Ab-Kadir, "Battery Backup Power System for Electrical Appliances with Two Options of Primary Power Sources," in *2018 IEEE 5th International Conference on Smart Instrumentation, Measurement and Application (ICSIMA)*, Songkla, Thailand: IEEE, Nov. 2018, pp. 1-5. <https://doi.org/10.1109/ICSIMA.2018.8688757>
- [4] A. H. Sabry, W. Z. Wan Hasan, F. Hani Nordin, and M. Z. Abidin Ab-Kadir, "Stand-alone backup power system for electrical appliances with solar PV and grid options," *IJEECS*, vol. 17, no. 2, p. 689, Feb. 2020, <https://doi.org/10.11591/ijeecs.v17.i2.pp689-699>
- [5] K. Garbesi, V. Vossos, and H. Shen, "Catalog of DC Appliances and Power Systems," *LBNL--5364E*, 1076790, Oct. 2010. <https://doi.org/10.2172/1076790>
- [6] Zhao Ma, Yahui Li, Yuanyuan Sun, and Kaiqi Sun, "Low Voltage Direct Current Supply and Utilization System: Definition, Key Technologies and Development," *CSEE JPES*, 2023, <https://doi.org/10.17775/CSEEJPES.2022.02130>
- [7] D. Bozalakov, M. J. Mnati, J. Laveyne, J. Desmet, and L. Vandevelde, "Battery Storage Integration in Voltage Unbalance and Overvoltage Mitigation Control Strategies and Its Impact on the Power Quality," *Energies*, vol. 12, no. 8, p. 1501, Apr. 2019, <https://doi.org/10.3390/en12081501>
- [8] D. Han, C. K. Song, G. Lee, W. Song, and S. Park, "A Comprehensive Review of Battery-Integrated Energy Harvesting Systems," *Adv Materials Technologies*, vol. 9, no. 21, p. 2302236, Nov. 2024, <https://doi.org/10.1002/admt.202302236>
- [9] A. Farakhori, D. Wu, Y. Wang, and H. Fang, "A Novel Modular, Reconfigurable Battery Energy Storage System: Design, Control, and Experimentation," *IEEE Trans. Transp. Electrification*, vol. 9, no. 2, pp. 2878-2890, Jun. 2023, <https://doi.org/10.1109/TTE.2022.3223993>
- [10] P. Pal, D. K. R., and P. S., "Design of Battery management system for Residential applications," *IJETT*, vol. 68, no. 3, pp. 12-17, Mar. 2020, <https://doi.org/10.14445/22315381/IJETT-V68I3P203S>
- [11] P. Rahmani et al., "Driving the future: A comprehensive review of automotive battery management system technologies, and future trends," *Journal of Power Sources*, vol. 629, p. 235827, Feb. 2025, <https://doi.org/10.1016/j.jpowsour.2024.235827>
- [12] S. Surya, V. Rao, and S. S. Williamson, "Comprehensive Review on Smart Techniques for Estimation of State of Health for Battery Management System Application," *Energies*, vol. 14, no. 15, p. 4617, Jul. 2021, <https://doi.org/10.3390/en14154617>
- [13] J.-Y. Bae, "Over-Temperature-Protection Circuit for LED-Battery Power-Conversion System Using Metal-Insulator-Transition Sensor," *Energies*, vol. 13, no. 14, p. 3593, Jul. 2020, <https://doi.org/10.3390/en13143593>
- [14] A. Kwasinski and P. T. Krein, "Stabilization of constant power loads in Dc-Dc converters using passivity-based control," in *INTELEC 07 - 29th International Telecommunications Energy Conference*, Rome, Italy: IEEE, 2007, pp. 867-874. <https://doi.org/10.1109/INTELEC.2007.4448903>
- [15] I. Hamidah et al., "Overcoming voltage fluctuation in electric vehicles by considering Al electrolytic capacitor-based voltage stabilizer," *Energy Reports*, vol. 10, pp. 558-564, Nov. 2023, <https://doi.org/10.1016/j.egy.2023.07.009>
- [16] W.-T. Sung and J.-S. Lin, "Design and Implementation of a Smart LED Lighting System Using a Self Adaptive Weighted Data Fusion Algorithm," *Sensors*, vol. 13, no. 12, pp. 16915-16939, Dec. 2013, <https://doi.org/10.3390/s131216915>
- [17] S. Mischos, E. Dalagdi, and D. Vrakas, "Intelligent energy management systems: a review," *Artif Intell Rev*, vol. 56, no. 10, pp. 11635-11674, Oct. 2023, <https://doi.org/10.1007/s10462-023-10441-3>
- [18] Y. Hao, D. Yi, X. Zhang, W. Yu, J. Xi, and L. He, "A Power Management IC Used for Monitoring and Protection of Li-Ion Battery Packs," *Journal of Sensors*, vol. 2021, no. 1, p. 6611648, Jan. 2021, <https://doi.org/10.1155/2021/6611648>
- [19] R. R. Al-Taie and X. Hesselbach, "Cost-Effective Power Management for Smart Homes: Innovative Scheduling Techniques and Integrating Battery Optimization in 6G Networks," *Electronics*, vol. 13, no. 21, p. 4231, Oct. 2024, <https://doi.org/10.3390/electronics13214231>
- [20] Z. Li, A. Yang, G. Chen, N. Tashakor, Z. Zeng, A. V. Peterchev, and S. M. Goetz, "A rapidly reconfigurable DC battery for increasing flexibility and efficiency of electric vehicle drive trains," *IEEE Transactions on Transportation Electrification*, vol. 10, no. 2, pp. 2322 - 2331, Jun. 2024, <https://doi.org/10.1109/TTE.2023.3239416>

- [21] J. Issa, "Display power analysis and design guidelines to reduce power consumption," *Journal of Information Display*, vol. 13, no. 4, pp. 167-177, Dec. 2012, <https://doi.org/10.1080/15980316.2012.743487>
- [22] S. M. Hashmi, S. Noor, and W. Parveen, "Advances in water splitting and lithium-ion batteries: pioneering sustainable energy storage and conversion technologies," *Front. Energy Res.*, vol. 12, p. 1465349, Jan. 2025, <https://doi.org/10.3389/fenrg.2024.1465349>