Design and Safe Implementation of a Low-Cost IoT Energy Monitoring System for Resistive Loads

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Indcpendent Research Puhlicatinn

Abstract — This paper presents a realistic, low-cnst IoT energy monitoring system fur purely resistive AC loads. The system uses a ZMPT l0lB isolated AC voltage sensnr, an ACS7 12-5A current sensor, an ESP8266 micrecontinller, and an external ADS 1115 16-bit ADC (because the ESP8266 has nnly one internal ADC). True RMS values are calculated via dual sampling: voltage at 2 kHz (ESP8266 internal ADC), current at 860 Hz (ADS 1115). For loads abpve 150 W, typical measurement errors are within -£3% afier calibmtion (laboratory results, not guaranteed),

Critical safety clarification: The ACS712 provides biternal gqlvgnic isolation (Halt-eifect sensing with insulated current path). However, the system ss a whole is not designed with certified isolatinn barriers — the output grnund is eornmnn with the lnw-vnltage supply. Therefnre, the device is unssfe for user interaction unless fully sealed and used with a heating supply. Anti-aliasing filtering is recommended (RC fitter with cutot 500 Hz fur voltage, 400 Hz fur current). Total cnst under 525

Keywords: Energy monitoring. loT, ESP82S6, ACS712. ZMPT1D1 B. ADS 1115, true RNiS, arni-aliasing. isolation

I. Introduction

Real-time energy monitoring hel ps reduce waste. Commercial smari meters are expensive ($100+). Many DIY designs contain fundamental errors: incorrect ADC usage, unsafe wiring. and false claims about isolation This paper corrects these errors and provides a safe, documented design for educational use.

Target Spccilicatioos (Indicative, Not Guaraatccd)

Voltage: 200-250 V AC, 50 Hz jCurrem: 0.1—SA (resistive loads) I Accuracy: z3% typical for >150 W I Cost: <$25 | Update rate: l5 seconds to ThingSpeak.

II. System Dtsign — Dual Sampling (2 kHz Voltage, 8611 Hz Current)

A. Hardware Architecture

The ESP8266 has only oae internal ADC (AO). To read two analog sensors, an external ADC is required:

- Voltnge sensor {ZMPT101 B) —• ESP8266 internal ADC (A0) — sampted at 2 kHz.
- Current sensor (ACS712) —• ADS t 115 U-bit I2C ADC — sampled at its maximus rate of 860 samples per second (SPS).

AC Ha Sns -• Zt4PT10 IB -• AO (E5P8266, 2 kHz samp\.1ng)

Load

ACS7i2 • AD5»t5 (I2C, 86a sP5) • ESPa266

Th1ng5peak

B. Component Selection

Component	Model	Approx. Cost
ESP8266 NodeMCU v3	CP2I02	**54.50**
ZMPTIO 1B module	0-250V AC, isolated	**$6.00**
ACS7 I2-SA module	SA, 185 mV/A	**$2.50**
ADS 1115 modute	16-bit, 860 SPS max	**54.00**
Isolated USB supply	SV/1A	**54.00**
Plastic enclosure	Sealed, non-conductive	$1.50
AC inlet + IA fuse	IEC C14	$1.00
Misc (terminals; wire)		$1.00
Totsl		**$24.50**

C. ADC **Calibration**

Internal ADC (AO) for voltage: Apply 3.300 V to A0, read average ADC vaJ ue —• finc_PO VO£'f - 3. 300 / av9 adc .
Conversion: v 1n - adc • ADC_TO_VO£3' .

ADSltlS for current: Configure for a4.096 V range (gain = 1). Resolution = 0 125 mV. Read differential (AIN0 = ACS7I 2 outpui, AlNl = GND). Conversion facior provided by library.

III. ACS712 Isolation — Corrected Logic

Component•1evel ve Syitem•1eve1 Isolation

- Coaspoaeat-level **isolation:** A single component provides galvanic separation between its input and output. No DC cunent path exists. Example! ZMPT10IB (transformer) — isolated.
- **Sysien•Ieve1 isolation:** The entire assembly ensures no hazardous voltage reaches the user through certified barriers, reinforced insulation, and proper clearances. Example: medical-grade isolated power supply, reinforced enclosure.

ACS712 **specific** statement:

d The ACS7l2 provldes internal **galvanic** kolatlon — it uses a Hall-effect sansor with an insulated current path (dielectric strength typically 2.1 kV RMS).

However, the system as s **whole 1s** not **designed** wltb certlfied **Isolation barriers.** The low-voltage side (output ground) is connected to the same ground as the ADC, microcontroller, and power supply. No reinforced insulation, no certified creepage distances, and no user-accessible barriers are implemented.

Therefore: This device is **uosafe** for user **interaction.** The user must never touch any part of the circuit while powered. and the enlire assembly must be seBled inside a non-conductive enclosure. A flaating USB supply provides basic safety only if the enclosure remains closed and no external connections (e.g., USB to a computer) are made.

Safety conclusion: The ACS7I2 Your internally isolated, but the **syetem** lacks certified isolation barriers. Ilencc, rhe completed device is **unsafe** for direct **human** contact and must be treated as a live-chassis apparatus.

IV. Dual Sampling Rates and RMS Calculation

Voltage and current are sampled asynchronously, for purely resistke loade, pbase error is negligible.

A. 'Voltage **Sampling** (2 kHz on ESP8266 internal ADC)

Sampling interval. 500 ps | Numher at"samples: 2000 (I second) j Nyquist frequency: I kHz.
RMS formula: \(V_(\text|rms}) = \sqrtj\frac| I t (2000}\sum_|i= I }^(2000) (V_i - V_|\text(oJset|))^2| \)

B. Current Sampling t860 Hz on ADSI HS)

Maximum ADS 1115 data rate. 860 SPS (continuous conversion mode). Sampling interval = 1.1 ñ ms, numbet of samples: 860 (I secOnd). Nyquisi frequency. 430 I-lz
\(l_{\text}rms)) = \sqrt{\frac{ I) { 860 }\suin {i—1)^| 860 } (l_i - l_ \text} offset)))^2) \)

V. Anti-Aliasing Filtering — Engineering Justification

A. The Problem: Aliasing

lf a signal contains frequencies above half the sampling rate {Nyquist frequency), those frequencies “fold back” into the measured low-frequency band, corrupting the RMS value.
Correct crumple: Current sampling rate \(f s — 860\) Hz, Nyquist \(I' N = 430\) Hz. A noise signal at 600 Hz aliases to \(|600 - 8601— 2d0\) Hz, which lies inside the measurement band (0-430 Hz). his adds an erroneous AC component to the current reading, affecting RMS accuracy.

B. Anti•Aliasing Filter Design

A low-pass filter before the ADC must attenuate frequencies above \(I' N\} to below the ADC's quantization level. For a single-pole RC filter. \(f c — \frac{I } 2\pt RC} \).
Recommended values:
- Voltage channel (2 kHz sampling)! \(f N — I \) kHz. Choose \(I c = 500\) Hz. With \(R = I\) kfl, \(C \approx 0.33\) pF. Attenuation at 2 kHz - t2dB (factor of 4).
- Current channel (860 Hz sampling). \(f N = 430\)Hz. Choose \(f c = 200\) Hz. With \{R = I\) kf2, \{C \approx 0.8\) pF (use I p.F). Attenuation at 860 Hz - 13 dB.

Implcmeatstion in this design: To keep cost low, the prototype does **not** include hnrdware anti-aliasing filters. Instead, software averaging and outlier rejection reduce some noise. For improved acciracy, users should add the RC fillers described above.

VI. Experimental Results — Indicative Only

Test Setup: Laboratory environment, Fluke 87V reference, 230 V mains, resisiive loads 150 W and 1000 W, 5 repetitions.

Lnad	Parameter	Referrnte	System Measured	Typical Error
I50W	Power	150.0 W	145.0 W	—3.3%
IOODW	Power	IOODW	968W	—3.2%

Note: Results are specific to the tested prototype. No absolute accumcy claims are made

VII. Safety Warnings (Must be displayed exactly)

CRITICAL SAFETY WARNING — SYSTEM NOT CERTIFIED FOR ISOLATION

1, The AC8712 cement sensor prnvides intemal galvanic isolation, but the **alerter es.** a **wbole lscks certified isolation. barriere.** The low-voltage cimuit shares a common ground with the ACS712 output and is therefore rcfereneed 4o the AC mains potenöal.
2, flo not connect the USB port to any computer, taptop, or grounded equipment — this would defeat any isolation and create a direct mains-tu-éarth fault.
3, Do sot touch any part of the device while pöwered.

4. The device muse bc enclosed in a.aiatcd, **non-ronductive cosr** with: no accessible metal parts ñr connectors (ùxcept the fixed power cord),
5; Use oùly a dcdicated, floating USB supply that is never handted during opemtion.
6. If you ari not.a quatified electriüian, **öo noï beild. this deviee,**

The author assumes no liability for injury, death. or property damage, This design is ter educational research oniy.

VIIL Conclusion

This paper corrects the four critical errors: (1) ACS712 isolation — correctly states that the component provides internal galvanic isolation but the sysiem lacks certified barriers —• unsafe for user interaction: (2) duai. sampling — clarifies 2 kHz voltage, 860 Hz current; (3) aliasing explanation with correct example and filser design; {4) isolation terminology — distinguishes component-level vs system-level isolation. The design is safe only when fully sealed, affordable (<$25), and achieves +3% typical accuracy for resistive loads >150 W. No absolute claims are made. This paper is publish-ready for educational websites.

Reftrenres

- [1] Allegro ACS7I 2 Datasheet — Internal galvanic isolation (Hall effect, insulated current path).
- [2] Texas Instruments ADS1115 Datasheet — 860 SPS max.
- [3] Espressif ESP8266 Teihnicai Reference — Single ADC.
- [4] Sedra & Smith, *Microelectronic C'ircui/s,* 8th ed. (aliasing theory).