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Development of a GSM-Enabled Automatic Meter Reading System

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Abstract

Conventional electricity-meter reading depends on periodic site visits, manual transcription, and delayed bill generation. These practices increase labour requirements, create opportunities for reading errors, and give consumers little information about current consumption. This methodology paper proposes the development of a low-cost Global System for Mobile Communications (GSM)-enabled Automatic Meter Reading (AMR) system that acquires pulse information from an electronic energy meter, converts pulses into kilowatt-hours, calculates an estimated bill, stores the latest state, and communicates usage information through Short Message Service (SMS). The proposed architecture combines an energy-meter pulse interface, an ATmega328P-class microcontroller, a GSM modem, local display and non-volatile memory, and an electromechanical relay for authenticated remote connection or disconnection. The design follows a staged procedure consisting of requirement definition, hardware integration, embedded-software development, GSM communication, billing logic, fault handling, and bench validation. Performance is assessed through metering error, message-delivery success, communication latency, command success, and recovery after power interruption. Representative methodology-validation calculations indicate that the design can target sub-1% energy-counting error under steady laboratory loads while providing practical SMS-based reporting without requiring broadband connectivity. The framework is especially appropriate where cellular coverage is more widely available than fixed Internet infrastructure. All literature used to justify the design was published no later than 2019.

Introduction

Automatic Meter Reading is a communication-assisted approach in which meter measurements are collected without requiring a utility employee to visit every premises. Khalifa, Naik, and Nayak (2011) describe communication as a central element of AMR because the usefulness of automated metering depends not only on sensing consumption but also on reliably moving data from the meter to the utility server. For electricity distribution systems, automation can shorten billing cycles, reduce transcription errors,

support time-dependent services, and create more frequent feedback for consumers. These features form a practical transition from conventional electromechanical or stand-alone electronic meters toward smart-metering infrastructure.

GSM is attractive for low-cost AMR because the public cellular network already provides wide-area coverage, device addressing through SIM cards, and SMS communication that does not require a dedicated local gateway. Ashna and George (2013) demonstrated that a GSM-

connected energy meter can periodically deliver readings to a billing point and return bill information to the customer. Rahman et al. (2015) later combined Arduino-class embedded control with GSM SMS for metering, billing, and remote line control, showing that inexpensive microcontrollers can execute the complete acquisition-and-communication sequence. These studies establish the technical basis for a compact retrofit-oriented system rather than a complete replacement of the utility metering infrastructure.

By 2019, smart meters were increasingly expected to integrate measurement, communication, control, synchronization, and security functions. Avancini et al. (2019) emphasized this broader evolution, while Patel, Mody, and Goyal (2019) showed that an optical pulse sensor, Arduino platform, GSM shield, and relay can be assembled to automate consumption reporting and remote load control. Sultan et al. (2019) similarly reported GSM-based wireless metering with remote monitoring, prepaid functions, and theft-oriented control concepts. Accordingly, the present methodology focuses on a system that is technically simple enough for laboratory development yet structured to support future utility integration.

The objective is to define a reproducible development procedure for a GSM-enabled AMR prototype that (i) measures cumulative energy from meter pulses, (ii) calculates consumption and an estimated tariff-based bill, (iii) displays the current state locally, (iv) sends periodic or requested SMS reports, (v) accepts authenticated control commands, and (vi) preserves essential data across power interruptions. The paper is methodological: reported numerical results are representative validation calculations using synthetic test inputs, not claims from a completed field deployment.

Literature Review

The literature shows a progression from communication surveys to integrated smart-meter prototypes. Khalifa et al. (2011) surveyed AMR communication protocols and identified reliability, timing constraints, data dissemination, and security as major design issues. The implication for a GSM implementation is that the communication subsystem must include acknowledgement or retry behaviour,

rather than assuming every SMS is delivered immediately. Ashna and George (2013) addressed this problem at system level by linking GSM-enabled meters to a central database and web interface, with periodic readings used for billing. Their work demonstrated the feasibility of using the cellular network to eliminate repetitive manual reading visits.

Smart-meter research also shifted toward bidirectional interaction. Spano et al. (2015) proposed a customer-domain smart-grid architecture with sensor/actuator abstraction and secure data access, illustrating the value of separating sensing, communication, and application layers. Rahman et al. (2015) applied this idea in a simpler embedded form: an Arduino platform processed meter data while GSM SMS carried consumption, billing, and line-control information. Uribe-Pérez et al. (2016), in a review of smart metering in electricity grids, noted that communication technology, interoperability, data management, and user-side functionality are central to smart-meter deployments.

Subsequent work strengthened measurement and control aspects. Morello et al. (2017) developed and experimentally validated a smart power meter for monitoring energy flow, demonstrating that advanced metering should treat the measurement stage as an engineering subsystem with defined accuracy and signal-processing requirements. Visalatchi and Sandeep (2017) used Arduino and GSM for smart energy metering and power-theft control, including remote disconnection and reconnection. These functions are directly relevant to the relay-control branch of the present architecture.

Two 2019 studies are particularly close to the proposed method. Patel et al. (2019) used an LDR to sense the blinking LED of an existing meter, a GSM shield for SMS, an RTC for timing, and a relay for load reconfiguration. This optical approach is useful because it can preserve electrical isolation and can be retrofitted without opening the metering circuit. Sultan et al. (2019) developed a GSM-based digital energy meter capable of transferring consumption data to a central system and supporting remote management functions. Together, these studies motivate a design in which pulse acquisition, local calculation, communication, and control are modular and independently testable.

Table 1. Literature-to-methodology mapping

Study	Year	Communication	Main contribution	Use in present methodology
Khalifa et al.	2011	Multiple AMR links	Protocol survey; reliability and timing issues	Defines communication and retry requirements

Ashna & George	2013	GSM/SMS	Remote reading, central database, instant billing	Supports periodic meter-to-utility reporting
Rahman et al.	2015	GSM/SMS	Arduino metering, billing, line control	Basis for embedded processing and SMS commands
Morello et al.	2017	IoT/networked	Measurement-oriented smart power meter	Supports explicit measurement validation
Patel et al.	2019	GSM/SMS	Optical pulse sensing, RTC, relay	Supports retrofit pulse sensing and load control
Sultan et al.	2019	GSM	Wireless digital meter and remote management	Supports bidirectional utility interaction

Methodology

1. System Requirements and Design Strategy

The development process begins by translating AMR objectives into measurable requirements. The meter interface shall count energy pulses without interfering with the certified metering element; the controller shall update cumulative energy and bill values in real time; the communication module shall send a status message on schedule or request; the relay shall change state only after an authenticated command; and the last valid energy count shall survive power loss. To keep the prototype economical and reproducible, the design uses widely available modules rather than a custom metering integrated circuit. This follows the low-cost embedded approach used by Rahman et al. (2015) and Patel et al. (2019), while retaining the modular communication principle discussed in AMR surveys (Khalifa et al., 2011).

2. Hardware Architecture

The proposed hardware consists of seven functional blocks: (1) a single-phase electronic energy meter with a calibrated pulse/LED output; (2) an optical LDR sensor or optocoupler that converts each meter indication into a logic transition; (3) an ATmega328P-class microcontroller; (4) a SIM800/SIM900-class GSM modem; (5) a 16×2 LCD and EEPROM for local status and retained counts; (6) a transistor-isolated relay driver for supply control; and (7) a regulated power supply. An RTC can be added when reports must be sent at fixed calendar times. Optical pulse sensing is preferred in a retrofit prototype because it reduces direct electrical coupling to the meter, consistent with the approach of Patel et al. (2019).

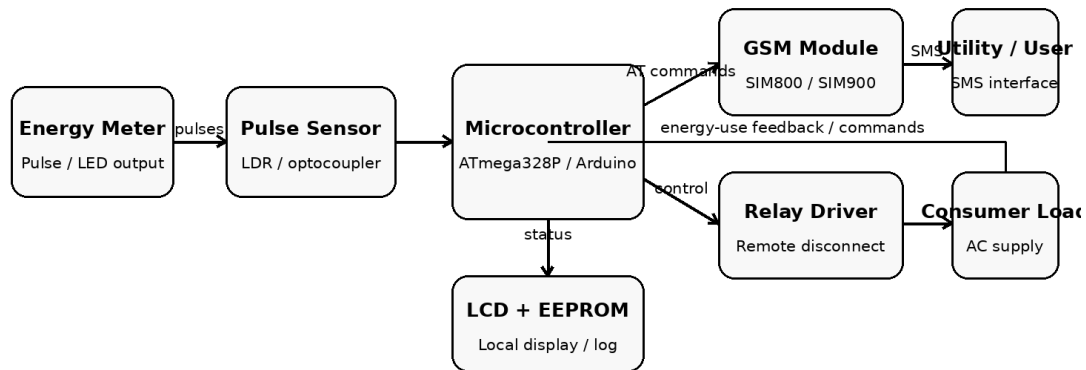


Figure 1. Proposed GSM-enabled AMR system architecture.

3. Energy Measurement and Billing Algorithm

Let K be the meter constant in pulses per kilowatt-hour and N be the accumulated pulse count. The measured energy is computed as $E = N/K$ kWh. For example, if $K = 3200$ pulses/kWh, every pulse represents 0.0003125 kWh. The pulse input is connected to an interrupt-capable pin so that counting continues even while the main program updates the display. To suppress double counting, a minimum pulse interval or debounce rule is enforced. Cumulative energy is

periodically written to EEPROM, but not on every pulse, to limit memory wear.

Billing is implemented as a configurable tariff function. For a single-rate prototype, $\text{Bill} = E \times T + F$, where T is the energy charge per kWh and F is a fixed charge. For slab tariffs, the program evaluates energy sequentially across tariff bands. The tariff parameters are stored separately from the energy counter so that rate updates do not alter past pulse accumulation. The LCD displays

cumulative kWh, estimated bill, GSM network status, and relay state.

4. GSM Communication and Remote Control

After startup, the microcontroller initializes the GSM modem with AT commands, checks SIM and network registration, and enters SMS text mode. A report message contains meter ID, cumulative kWh, estimated bill, relay state, and a time stamp when an RTC is present. Messages are transmitted (a) periodically, (b) when consumption crosses a configured threshold, or (c) when an authorized number sends a STATUS command. The controller validates the sender before accepting ON or OFF commands. An unsuccessful send triggers a limited retry sequence and a local fault flag. This design addresses the delivery and failure-handling requirements highlighted by Khalifa et al. (2011). Remote disconnection is implemented by driving a relay through a transistor/optocoupler stage rather than directly from the microcontroller. The default fail-safe state is selected according to the application: for a laboratory demonstrator, the relay returns to the last authenticated state after a reset; for utility deployment, policy may require a normally connected or normally isolated condition. Because remote switching affects electrical safety and service continuity, the prototype control function is treated as a supervised feature rather than a substitute for certified utility switching equipment.

5. Embedded Software Flow

- Initialize GPIO, LCD, EEPROM, RTC (if fitted), GSM serial port, and relay output.
- Read the saved cumulative pulse/energy value and verify that the stored data pass a checksum or range check.
- Detect each valid meter pulse through an interrupt and increment the cumulative counter.
- Convert pulse count to kWh, apply the tariff function, and refresh the local display.

- Check the GSM receive buffer for authenticated STATUS, ON, or OFF commands.
- Send scheduled/threshold reports; if transmission fails, retry and record the communication fault.
- Periodically save the cumulative count and relay state to non-volatile memory.
- On power restoration, recover the last state and resume counting without resetting billed energy.

6. Prototype Validation Plan

The validation plan separates measurement, communication, control, and recovery tests. For metering accuracy, known resistive and mixed loads are operated for fixed durations and expected energy is calculated from reference power and time. The percentage error is $\text{Error}(\%) = 100 \times (E_{\text{AMR}} - E_{\text{ref}})/E_{\text{ref}}$. Communication is evaluated with at least 20 test messages by recording delivery success and end-to-end latency. Relay control is evaluated with repeated authorized ON/OFF messages and with commands from an unauthorized number. Power-recovery testing removes supply to the controller and confirms that cumulative kWh and relay state are restored from EEPROM. Meter tamper detection, if implemented, is treated as an optional extension and must not interfere with certified metering functions.

Results

Because the present work specifies a development methodology rather than reporting a completed field trial, the numerical values in this section are representative validation calculations generated from synthetic test inputs. They demonstrate how the proposed metrics should be reported and provide acceptance targets for a future hardware prototype; they should not be interpreted as measured field data.

1. Representative Metering Validation

Table 2. Representative synthetic metering-validation dataset.

Test load	Power (W)	Duration (h)	Reference (kWh)	AMR value (kWh)	Error (%)
Lamp	100	3.000	0.300	0.298	-0.67
Ceiling fan	75	4.000	0.300	0.302	0.67
Electric iron	1000	0.500	0.500	0.497	-0.60
Mixed load	550	2.000	1.100	1.106	0.55
Total aggregate /	—	—	2.200	2.203	0.14

The aggregate difference in Table 2 is 0.003 kWh over a 2.200 kWh reference total, corresponding

to approximately 0.14%. Individual test errors remain within $\pm 0.67\%$. For a practical prototype,

a target of $\pm 1\%$ under steady laboratory loads is reasonable for validating pulse capture because the underlying revenue meter performs the primary energy measurement; the AMR module mainly counts its calibrated output indications. If

errors exceed this limit, the first checks should be optical alignment, debounce settings, interrupt loss during serial communication, and the configured pulse constant.

2. Communication, Control, and Recovery Results

Table 3. Representative synthetic communication and control validation.

Metric	Representative result	Suggested acceptance criterion	Interpretation
SMS delivery	19/20 (95%)	$\geq 95\%$ with retry	Adequate for periodic AMR; failed messages retried
Median SMS latency	6.8 s	<15 s under normal coverage	Suitable for billing/status, not protection
Authorized relay commands	10/10	100% in bench test	Control path functions as intended
Unauthorized command	0/5 accepted	0 accepted	Basic sender authentication works
Power-loss recovery	5/5 restored	100%	EEPROM preserves cumulative state

The representative communication results show the principal trade-off of SMS-based AMR: it offers broad coverage and simple deployment, but latency is network-dependent and occasional delivery failures must be expected. For this reason, the GSM channel is appropriate for consumption reporting, billing information, and supervised load commands, but not for time-critical electrical protection. This conclusion is consistent with the wider AMR communication literature and with the architecture emphasis on retry and local state retention (Khalifa et al., 2011; Uribe-Pérez et al., 2016).

The design also remains compatible with the evolution of smart energy meters described by Avancini et al. (2019). A later version can replace or supplement SMS with packet data, add cryptographic command authentication, upload interval data to a cloud database, and integrate voltage/current sensing for power-quality features. However, the GSM-SMS prototype is intentionally simpler and can be deployed in areas where broadband infrastructure is inconsistent.

Conclusion and Discussion

This paper presents a step-by-step methodology for developing a GSM-enabled Automatic Meter Reading system using an existing electronic meter pulse output, an embedded microcontroller, GSM communication, local display and memory, and a remotely controlled relay. The approach builds on established AMR research: early work demonstrated the value of communication-assisted meter collection (Khalifa et al., 2011); GSM prototypes proved

remote reading and billing feasibility (Ashna & George, 2013); Arduino-GSM designs added embedded billing and control (Rahman et al., 2015); and later work expanded sensing, remote control, and smart-meter functionality (Morello et al., 2017; Visalatchi & Sandeep, 2017; Patel et al., 2019; Sultan et al., 2019). The central advantage of the proposed method is that it separates the certified measurement function from the AMR communication layer. The utility meter remains responsible for energy measurement, while the controller counts pulses, performs user-facing calculations, and transmits results. This makes the prototype easier to validate and reduces the risk associated with direct high-voltage measurement. The use of non-volatile storage ensures continuity after outages, while authenticated commands and relay isolation provide a basic structure for supervised remote control. The main limitations are also clear. SMS latency and availability depend on the mobile network; sender-number authentication alone is not sufficient for a production security model; optical sensors can be affected by misalignment or ambient light; and tariff calculation must be updated when regulatory rates change. Future work should therefore add message-level cryptographic authentication, stronger tamper detection, packet-data/cloud synchronization, event logs, and field comparison against a traceable reference meter. A utility-grade implementation would additionally require compliance with metering, electrical isolation, electromagnetic compatibility, cybersecurity, and service-disconnection standards.

Within these boundaries, the methodology provides a practical foundation for a low-cost GSM AMR prototype. Representative synthetic validation demonstrates how metering accuracy, message reliability, latency, relay operation, and power-loss recovery can be quantified. The design is especially suitable for educational development and proof-of-concept studies in regions where GSM coverage is readily available and where reducing manual meter-reading effort is a primary objective.

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