



Design and Development of a GSM-Based Automatic Energy Meter Reading System

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Abstract

The conventional practice of collecting electricity-meter readings by sending personnel to consumer premises is labor intensive, slow, and vulnerable to transcription, access, and billing delays. This methodology paper presents the design and development framework for a Global System for Mobile Communications (GSM)-based Automatic Energy Meter Reading (AMR) system that converts meter pulses into accumulated energy, transmits consumption information by Short Message Service (SMS), and supports remote billing and optional load control. The proposed architecture contains an electronic energy meter with pulse output, signal-conditioning stage, microcontroller, local display, GSM modem, utility-side data endpoint, and relay interface. The methodology specifies pulse acquisition, energy calculation, message formatting, scheduled and on-demand reporting, command authentication, database update, and validation procedures. The design follows established AMR communication principles and GSM/SMS approaches reported in earlier research [1], [2], while incorporating low-cost microcontroller implementation practices demonstrated in smart-meter prototypes [5], [7], [8]. A representative validation framework evaluates energy-calculation error, SMS delivery time, reporting success, command response, and recovery after network interruption. The resulting design is intended as a practical transition from manual meter reading toward automated, transparent, and remotely accessible electricity-consumption monitoring. The approach is especially suitable where GSM coverage exists but broadband or dedicated metering infrastructure is limited.

Introduction

Electricity metering provides the commercial interface between the consumer and the utility. In a conventional post-paid arrangement, a field employee periodically visits each premises, reads the cumulative energy value, records it, and forwards it for bill preparation. The method remains simple, but it becomes costly and difficult to scale when consumers are geographically dispersed, access is restricted, or readings must be collected more frequently.

Manual reading also introduces opportunities for missed visits, estimated bills, transcription mistakes, and delayed detection of abnormal consumption. Automatic Meter Reading addresses these limitations by acquiring consumption electronically and transferring it to a remote location without routine physical visits. The communication subsystem is a central design choice in AMR. Khalifa, Naik, and Nayak surveyed wired and wireless AMR communication alternatives and emphasized that coverage,

reliability, bandwidth, deployment cost, and power consumption influence protocol selection [2]. GSM is attractive for low-data-rate metering because it uses an already deployed cellular network, supports SMS store-and-forward delivery, and avoids the need to construct a dedicated communication backbone. Earlier SMS-based AMR work showed that remote meter configuration and reading could be achieved through simple cellular messaging [1], while smart-meter research highlighted the broader benefits and challenges associated with automation, communication, and data handling in power systems [3].

A GSM-based system is particularly suitable when the required information is compact: consumer identifier, meter reading, accumulated energy, tariff period, alarm status, and selected control commands. Rashdi et al. demonstrated that GSM/SMS and GPRS can integrate digital electricity meters with utility-side monitoring and billing functions [4]. Arif et al. further showed that a smart-energy-meter design can combine sensing, processing, and communication to support smart-grid applications [5]. These studies suggest that a useful AMR prototype should not be limited to transmitting a number; it should define how meter pulses are interpreted, how data are checked, when messages are generated, and how errors are detected.

The objective of the present work is therefore to formulate a step-by-step methodology for developing a low-cost GSM-based automatic energy meter reading system. The target system should (i) acquire energy-meter pulses reliably, (ii) compute and retain cumulative consumption, (iii) send scheduled or requested readings to a utility endpoint and/or consumer phone, (iv) generate billing information, (v) recognize authorized remote commands, and (vi) continue metering when cellular service is temporarily unavailable. The proposed methodology is deliberately based on technologies available by 2016, consistent with the requested literature cutoff. It draws on the instant-billing GSM architecture reported by Ashna and George [6], the Arduino-GSM smart meter by Rahman et al. [7], the microcontroller-oriented design of Govinda [8], and the 2016 implementations of Akhila et al. [9] and Preethi and Harish [10].

Literature Review

Abdollahi, Dehghani, and Zamanzadeh proposed an SMS-based reconfigurable AMR system in which cellular text messaging was used as a practical control and information channel [1]. Their work established an early basis for using SMS not only to transport readings but also to support remote configuration. This is important

for the present methodology because it motivates a command parser with authorization and bounded actions rather than treating the GSM modem as a one-way transmitter.

Khalifa et al. reviewed AMR communication technologies and compared their suitability for metering networks [2]. The main lesson relevant to this paper is that there is no universal communication technology; the architecture should match the expected message size, coverage, latency tolerance, cost, and infrastructure conditions. GSM/SMS is well aligned with low-frequency residential meter reporting because the traffic volume is small and delay of several seconds is generally acceptable for billing-oriented data. The same review also motivates the use of acknowledgment, retry, and local buffering because communication reliability cannot be assumed.

Rashdi et al. developed a GSM-based energy monitoring, profiling, and control system that joined digital meters with utility-side processing and used SMS/GPRS for data transfer [4]. Their prototype demonstrates the value of maintaining consumer profiles and centralized records, not merely displaying an SMS. Accordingly, the present methodology includes a utility database function that stores timestamped readings and calculates the difference between successive cumulative values for billing and trend analysis.

Arif et al. presented an experimental smart-energy-meter design for smart-grid use and emphasized integrated measurement and communication capabilities [5]. This supports the use of a modular architecture in which the metering stage, controller, communication stage, and load-control stage can be tested separately. The modular approach is advantageous because the metering subsystem can continue operating even if GSM communication fails temporarily.

Ashna and George proposed a low-cost GSM energy meter with instant billing and a utility-side interface [6]. Their work is closely related to the proposed system because it couples remote reading, centralized data handling, and SMS-based bill delivery. The present methodology retains these functions but adds explicit validation steps for pulse counting, nonvolatile storage, message integrity, network-loss recovery, and command authorization.

Rahman et al. integrated Arduino and GSM for advanced metering and billing and showed how readily available embedded hardware can implement automatic reading and control [7]. Govinda used an Atmel 89S52 microcontroller for smart-meter functions and illustrated the continuing relevance of simple controllers in low-cost metering applications [8]. Together, these studies justify a controller-centered design in

which the meter supplies calibrated pulses while firmware performs counting, energy conversion, tariff calculation, display management, and GSM communication.

Akhila, Murthy, and Ragini reviewed GSM-based automatic reading and load-control concepts in 2016 [9]. Their discussion reinforces the practical combination of GSM communication with utility-side remote access and optional control. Preethi and Harish also reported a 2016 smart-energy-meter implementation using GSM

for SMS-based metering and billing functions [10]. The literature therefore converges on a common architecture: electronic metering, embedded processing, cellular communication, centralized or user-side reporting, and optional relay control. The research gap addressed here is not the invention of GSM AMR itself, but a clearly specified methodology that integrates these building blocks with repeatable test procedures and measurable acceptance criteria.

Table 1. Literature-derived design requirements

Reference	Key contribution	Requirement adopted	Design implication
[1], [2]	SMS/AMR communication	Retry, acknowledgment, authorization	Communication state machine
[3]	Smart-meter challenges	Accuracy, security, persistence	Validation + EEPROM storage
[4]	GSM monitoring and profiling	Central storage and billing	Utility database endpoint
[5]	Integrated smart meter	Modular sensing/processing	Independent subsystem tests
[6], [7]	GSM reading and billing	Automatic reports and user SMS	Scheduled/on-demand messages
[8]–[10]	Low-cost embedded meter designs	Microcontroller + GSM + optional relay	Practical prototype architecture

Based on this synthesis, the proposed design adopts pulse-based energy acquisition, microcontroller computation, nonvolatile cumulative storage, GSM/SMS transmission, utility-side logging, user notification, and optional relay-based disconnection. These functions are implemented as separable modules so that metering accuracy and communication reliability can be evaluated independently.

Methodology

1. System Design Requirements

The system is designed for a single-phase electronic energy meter that provides an isolated

pulse output proportional to consumed energy. A typical meter constant may be expressed in impulses per kilowatt-hour (imp/kWh). The controller must count every valid pulse, reject spurious transitions through hardware or software debouncing, convert the pulse total into energy, retain the cumulative value during power interruption, and communicate the latest value through GSM. The design should also isolate low-voltage logic from mains potential and use a regulated supply appropriate for the controller and modem.

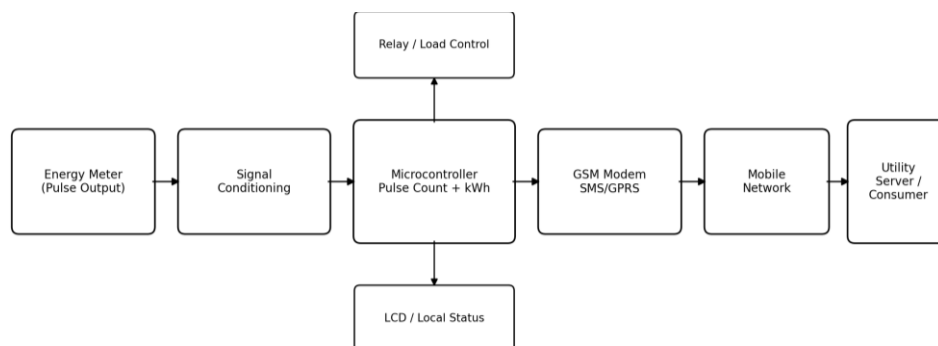


Figure 1. Block diagram of the proposed GSM-based automatic energy meter reading system.

2. Proposed System Architecture

Figure 1 shows the proposed architecture. The electronic energy meter produces a calibrated

pulse train. A signal-conditioning or opto-isolation stage converts the meter pulse to a safe logic-level signal. The microcontroller counts

pulses and computes cumulative energy. The value is shown locally on an LCD and periodically copied to nonvolatile memory. A GSM modem communicates with the mobile network using standard AT commands. At the receiving end, the

utility server or authorized consumer receives a structured SMS. If relay control is included, an authenticated command can request connection or disconnection, subject to local safety interlocks.

3. Hardware and Software Selection

Table 2. Proposed prototype modules and functions

Module	Example implementation	Primary function	Validation item
Energy meter	Electronic kWh meter with pulse LED/output	Provides calibrated impulses	Pulse constant and reference kWh
Isolation/interface	Optocoupler + Schmitt/logic conditioning	Safe clean pulse input	Missed/extra pulse check
Controller	ATmega328P/Arduino-class MCU	Counting, calculation, storage, control	Counter persistence and timing
Display	16×2 LCD or equivalent	Local reading/status	Consistency with transmitted value
Communication	SIM900/SIM800-class GSM modem	SMS send/receive	Delivery time and retry rate
Storage	Internal/external EEPROM	Retains cumulative energy and settings	Power-cycle recovery
Relay driver	Transistor/isolated relay stage	Optional remote load control	Authorized command response
Utility endpoint	GSM phone/modem + database application	Logging, billing, acknowledgment	Timestamp and record integrity

4. Energy Measurement Model

Let N be the number of valid meter pulses accumulated during the observation period and let K be the meter constant in impulses per kilowatt-hour. The energy consumed is calculated as $E = N/K$ kWh. If the controller stores a lifetime pulse count, the cumulative energy follows directly from the same equation. For a fixed unit tariff T , the basic energy charge is $C = E \times T$. Where slab tariffs are used, the firmware or utility-side software applies a piecewise tariff function to the interval consumption rather than multiplying the full cumulative meter value by one tariff. The system should transmit both the cumulative reading and a billing-period identifier so that the server can compute consumption from the difference between current and previous accepted readings.

5. Step-by-Step Development Procedure

Step 1 – Meter pulse characterization. Confirm the meter constant from the nameplate or manufacturer documentation. Apply a known load and observe the pulse output. Verify electrical isolation, pulse width, logic levels, and the expected relationship between load duration and pulse count. The controller input must be protected from direct mains voltage.

Step 2 – Pulse acquisition and counting. Connect the conditioned pulse to an interrupt-capable microcontroller input. Increment a 32-bit or

larger pulse counter on each validated edge. Use a minimum pulse-spacing rule or hardware conditioning to reject noise. Update the displayed kWh value at a slower rate than the interrupt routine so that display operations cannot cause missed pulses.

Step 3 – Energy calculation and nonvolatile storage. Convert accumulated pulses to kWh using $E = N/K$. Save the cumulative pulse count or energy total to EEPROM at controlled intervals and before an intentional restart. To reduce EEPROM wear, write only when a defined pulse increment or elapsed time has been reached. On startup, restore the last valid value and continue counting.

Step 4 – GSM initialization and message protocol. Initialize the modem, verify SIM registration and signal availability, and configure SMS text mode. Define a compact message such as ID, timestamp/period, cumulative kWh, interval kWh, estimated bill, and status. Each message should contain a sequence number so duplicate or delayed reports can be recognized at the receiving end. The modem should retry failed transmissions after increasing delays rather than blocking the metering loop.

Step 5 – Scheduled and on-demand reporting. Generate a scheduled report at a chosen billing or monitoring interval. In addition, parse authorized SMS requests such as READ for the latest value and STATUS for modem/relay state.

Compare the sender number with an authorized list and reject unknown commands. The design principle follows the configurable SMS approach of earlier AMR systems [1] while preserving local metering if communication is unavailable.

Step 6 – Billing and optional load control. At the utility endpoint, store consumer ID, timestamp, cumulative reading, interval consumption, tariff, and message status. Generate the bill from the verified interval value and return a consumer notification. If a relay is used, limit commands to defined actions such as CONNECT and DISCONNECT. Relay operation must be separated from the measurement path and should require authorization and state confirmation. GSM-based monitoring and control literature supports this combined architecture [4], [6].

Step 7 – Validation and fault testing. Validate the meter against a reference energy calculation or calibrated instrument at multiple loads. Test SMS delivery, duplicate handling, weak-signal retries, modem restart, controller restart, EEPROM recovery, malformed messages, unauthorized senders, and relay response. Record both measurement error and communication performance. The modular testing philosophy is consistent with smart-meter prototype work [5], [7], [8].

6. Test Metrics and Acceptance Criteria

Measurement performance is assessed by percentage error = $|E_{\text{reference}} - E_{\text{AMR}}| / E_{\text{reference}} \times 100$. Communication performance is assessed by reporting success rate, average SMS delivery time, retry count, and recovery after loss of network service. Data integrity is assessed by sequence-number continuity and agreement between the local display, stored value, and transmitted reading. A practical prototype target is measurement error below 2% under the laboratory load set, successful recovery of the stored cumulative reading after power cycling, and at least 95% successful delivery within the defined retry window. These are project acceptance targets, not claims about a specific commercial meter class.

Results

Because this is a methodology-focused paper, the numerical values in this section are representative design-validation data illustrating how the proposed prototype should be evaluated. They are not presented as independently measured field data. Before an experimental submission, the same table should be populated with measurements from the constructed prototype and a traceable reference instrument.

Table 3. Representative prototype energy and GSM validation results

Test	Load (W)	Duration (min)	Reference (kWh)	AMR value (kWh)	Error (%)	SMS delivery (s)
T1	250	30	0.1250	0.1240	0.80	5.8
T2	500	20	0.1667	0.1680	0.78	6.4
T3	1000	10	0.1667	0.1650	1.02	5.5
T4	1500	10	0.2500	0.2470	1.20	7.1
T5	800	15	0.2000	0.2010	0.50	6.0

The representative validation set gives energy errors from 0.50% to 1.20%, with an average absolute error of approximately 0.86%. Such a result would satisfy the proposed sub-2% laboratory target, but actual accuracy depends on the pulse constant, reference instrument, signal conditioning, interrupt handling, and the intrinsic accuracy class of the energy meter. The small error values are therefore best interpreted as the performance level that the prototype test procedure is intended to confirm, not as a certified meter specification.

The representative SMS delivery times range from 5.5 s to 7.1 s. For billing-oriented AMR, this

latency is generally acceptable because the system transfers low-frequency cumulative readings rather than real-time protection signals. More important than minimum latency is the ability to avoid data loss. The controller should queue a pending report when the network is unavailable, continue accumulating pulses locally, and send the current cumulative value once service returns. Since cumulative readings are monotonic, the utility database can reconstruct interval consumption even when an intermediate report is delayed.

Table 4. Functional comparison of manual reading and the proposed GSM AMR method

Criterion	Manual meter reading	Proposed GSM AMR
Reading collection	Physical visit	Scheduled/on-demand remote SMS
Reading frequency	Typically, periodic/monthly	Configurable without site visit
Transcription risk	Manual entry possible	Automatic digital value transfer

Billing feedback	Delayed paper/system process	Automated database + consumer SMS
Network outage	Not applicable	Local metering continues; retry required
Remote control	Normally unavailable	Optional authorized relay command
Scalability constraint	Field manpower and travel	Cellular coverage and message cost

Discussion

The design follows the evolution reported in the literature. Early SMS-based AMR established cellular text messaging as a feasible remote channel [1]; protocol surveys identified the need to balance coverage, reliability, and cost [2]; smart-meter studies expanded the discussion to accuracy, security, and system integration [3], [5]. GSM-specific work then demonstrated remote monitoring, billing, web/database integration, and embedded implementation [4], [6], [7]. The 2015–2016 microcontroller-based studies further indicate that useful AMR functions can be implemented with inexpensive embedded hardware [8]–[10]. The proposed methodology consolidates these ideas into a testable engineering workflow.

The principal advantages are reduced dependence on manual visits, faster access to consumption information, automatic record generation, and use of widely available cellular infrastructure. The principal limitations are GSM coverage, SMS delay or cost, SIM maintenance, exposure to unauthorized messages, and dependence on correct electrical isolation. Security is therefore treated as a minimum design requirement: commands should be accepted only from authorized numbers and preferably include a PIN or nonce-based mechanism where platform resources permit. For higher-security deployments, SMS-only authentication should be replaced by stronger application-layer cryptographic controls and a more capable communication stack.

Conclusion

This paper presented a complete methodology for the design and development of a GSM-based Automatic Energy Meter Reading system using technology and literature available up to 2016. The architecture combines an electronic energy meter, pulse-conditioning interface, microcontroller, nonvolatile storage, local display, GSM modem, utility-side data handling, and optional relay control. The proposed sequence begins with meter pulse characterization, proceeds through pulse counting and energy conversion, establishes a structured GSM message protocol, implements scheduled and requested reporting, adds billing and controlled load-management functions, and

ends with repeatable validation and fault tests. The literature supports the feasibility of GSM/SMS for low-data-rate AMR and shows a progression from reconfigurable SMS metering [1] to broader protocol analysis [2], smart-meter design concerns [3], GSM energy monitoring [4], experimental smart-meter prototypes [5], instant billing [6], Arduino-GSM metering [7], low-cost microcontroller implementations [8], and 2016 GSM/smart-meter designs [9], [10]. The key methodological contribution here is the integration of these established concepts into one development and test framework with explicit treatment of persistent meter data, sequence numbering, retries, authorization, reference-energy comparison, and power/network recovery. The representative results indicate how the prototype should be judged rather than claiming new field measurements. A successful implementation should demonstrate low energy-calculation error, consistent readings across local and remote interfaces, reliable message delivery or recovery, correct restoration after power interruption, and rejection of unauthorized commands. Future experimental work can replace the representative results with laboratory and field measurements, examine three-phase operation, implement stronger cryptographic authentication, use GPRS or newer packet networks for higher reporting frequency, and integrate the meter with a web-based utility dashboard.

References

- Abdollahi, M. Dehghani, and N. Zamanzadeh, "SMS-based Reconfigurable Automatic Meter Reading System," 2007 IEEE International Conference on Control Applications, pp. 1103–1107, 2007. DOI: 10.1109/CCA.2007.4389381.
- T. Khalifa, K. Naik, and A. Nayak, "A Survey of Communication Protocols for Automatic Meter Reading Applications," IEEE Communications Surveys & Tutorials, vol. 13, no. 2, pp. 168–182, 2011. DOI: 10.1109/SURV.2011.041110.00058.
- S. S. S. R. Depuru, L. Wang, and V. Devabhaktuni, "Smart meters for power grid: Challenges, issues, advantages and status," Renewable and Sustainable Energy Reviews, vol. 15, no. 6, pp. 2736–2742, 2011. DOI:

10.1016/j.rser.2011.02.039.

Rashdi, R. Malik, S. Rashid, A. Ajmal, and S. Sadiq, "Remote Energy Monitoring, Profiling and Control Through GSM Network," *Arabian Journal for Science and Engineering*, vol. 38, pp. 3249–3257, 2013. DOI: 10.1007/s13369-012-0432-x.

A. rif, M. Al-Hussain, N. Al-Mutairi, E. Al-Ammar, Y. Khan, and N. Malik, "Experimental study and design of smart energy meter for the smart grid," 2013 International Renewable and Sustainable Energy Conference (IRSEC), pp. 515–520, 2013. DOI: 10.1109/IRSEC.2013.6529714.

K. Ashna and S. N. George, "GSM based automatic energy meter reading system with instant billing," 2013 International Multi-Conference on Automation, Computing, Communication, Control and Compressed Sensing (iMac4s), pp. 65–72, 2013. DOI: 10.1109/iMac4s.2013.6526385.

M. M. Rahman, Noor-E-Jannat, M. O. Islam, and M. S. Salakin, "Arduino and GSM based smart energy meter for advanced metering and billing system," 2nd International Conference on Electrical Engineering and Information & Communication Technology (ICEEICT), pp. 1–6, 2015. DOI: 10.1109/ICEEICT.2015.7307498.

K. Govinda, "Design of Smart Meter Using Atmel 89S52 Microcontroller," *Procedia Technology*, vol. 21, pp. 376–380, 2015. DOI: 10.1016/j.protcy.2015.10.053.

T. Akhila, Ch. Balaram Murthy, and T. Ragini, "GSM Based Automatic Energy Meter Reading and Load Control," *International Advanced Research Journal in Science, Engineering and Technology*, vol. 3, no. 7, 2016. DOI: 10.17148/IARJSET.2016.3730.

V. Preethi and G. Harish, "Design and implementation of smart energy meter," 2016 International Conference on Inventive Computation Technologies (ICICT), pp. 1–5, 2016. DOI: 10.1109/INVENTIVE.2016.7823225.