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Design and implementation of low-cost universal smart energy meter with demand side load management

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Abstract: The authors propose, design, and implement a low-cost universal smart energy meter (USEM) with demand-side load management. The meter can be used in the postpaid and prepaid modes with flexible tariff plans such as time of use, block rate tariff, and their combination. The smart meter comprises of a potential transformer, current transformer, and microcontroller unit with an embedded communication module. The connectivity among the utility authority, the smart meter, and consumer is established by authority identification number, meter identification number, and user identification number using the cellular network. The load management option of the meter controls electrical loads and provides emergency power during the power shortage. The USEM can be configured and reconfigured remotely simply by short message service without changing hardware. Besides, energy consumption status, meter tampering, and fault at the distribution end can be monitored with the proposed metering system. Here, a prototype of the smart meter is presented, and its effectiveness, flexibility, and versatility are experimentally demonstrated.

1 Introduction

Smart energy metering system is highly demanded as it offers quick revenue collection, remote monitoring, and control of power distribution system. Since smart metering requires more features than what standard electromechanical or electronic metering system offers [1], automatic meter reading (AMR) system was introduced by combining the communication infrastructure with the electronic metering system. This combination expedites collecting meter information and hence provides a reliable and effective solution remotely [2]. However, the AMR-based metering system is not an efficient and affordable solution; while it replaces manual meter reading, it requires huge financial involvement to establish communication infrastructure.

In recent years, prepaid energy metering system has become very attractive to both consumer and power distribution authority as it is efficient, cost effective, and it enhances system accountability [3]. However, some challenging issues limit the attractiveness of prepaid energy metering, e.g. establishing vending station and network connectivity, handheld equipment for tariff plan setting and system upgradations, lack of interoperability and demand-side load management (DSLM), and incompatibility with micro-generation.

Advanced metering infrastructure (AMI)-based smart energy metering system with control devices, and a bi-directional communication link became quite popular as it solves several problems inherent in the old metering system [4]. The attractive features of the AMI-based metering system are DSLM, remote tariff plan setting, pricing, billing information, remote connection and disconnection, fault detection, tampering protection etc. AMI comprises of smart meter, user gateways, bi-directional communication system, and meter data management system [5].

The communication system of a smart meter is a crucial part as all functionalities are dependent on its qualities and available services [6]. In previous years, a significant research body proposed different types of communication protocols such as public switched telephone network, power line carrier (PLC) communication, Bluetooth, ZigBee, and WiFi [7–11]. In spite of being a popular and cost-effective system (as cabling infrastructures are available) [12], PLC technology has reliability issues due to noisy medium, high signal attenuation, susceptibility to interference from nearby devices, and high loss rate [13]. Bluetooth, WiFi, and Zigbee-based communication protocols have some deficiencies as they require complex infrastructure for having short distance coverage [13, 14]. Benzi *et al.* addressed specific architectures for a consumer-oriented implementation of a smart meter network using the combination of PLC, wireless, and web-based communication [15]. However, all of the proposed communication protocols are expensive and therefore not viable for cost-effective applications. Tan *et al.* [16] demonstrated automatic power meter reading system using cellular networks. Accordingly, every communication protocol has some pros and cons. It is thought that the use of established communication infrastructure could be the best cost-effective approach for a smart meter from controlling and monitoring point of view.

There are several techniques of DSLM including direct load control, incentivized tariff plan, rebates, and subsidies programme, and education programme that facilitate the efficient use of electricity for increasing energy demand [17–19]. Hu *et al.* [20] demonstrated hardware design of smart home energy management using dynamic price response, but they did not integrate it with the smart metering system. Energy management using the smart metering system and web server have been reported in [21]. Pereira *et al.* reported on consumer energy management system integrated with smart meters using supervisory control and data acquisition system/PLC network [22]. However, both papers have not been demonstrated practically. AMI-based smart metering allows for real-time dynamic pricing where the utility operator can charge variable prices depending on load demand [23].

Software update of smart energy meter is a crucial operation to amend and extend the features like mode switching and tariff planning as it involves security and reliability of the whole metering system. Giubbini [24] invented remote firmware update of the smart meter by transmitting programme from concentrator to the host controller of smart meter. Though it is an excellent work of remote software update, it requires complex circuitry and the PLC communication-based concentrator. However, the wired automation system is too expensive; thus it is not implemented on a large scale [25]. Also, this method is not feasible in third world countries where PLC communication infrastructure has not been constructed yet.

This article reports on the design and practical implementation of universal smart energy meter (USEM) with DSLM overcoming the limitations incurred by previous systems. The main contribution of this work is the development of hardware and software for the mode of payment configuration (prepaid–postpaid), DSLM, and remote tariff plan setting through authenticated short message service (SMS). Different monitoring and protection schemes such as over and under voltage protections, overload protection, tampering and bypassing alerts, recharging alert, automatic reconnection after disruption, and power factor monitoring are integrated with the USEM. Moreover, easy recharging via mobile phone top-up and balance adjustment feature are also integrated into the USEM.

This paper is organised as follows: Section 2 explains why cellular communication is preferred, Section 3 provides the background theory, Section 4 illustrates the proposed metering system, and Section 5 demonstrates the testing and operation of the proposed metering system. Finally, conclusions are drawn in Section 6.

2 Cellular communication: smart metering traffic

Cellular communication is a reliable and cost-effective option because of its widespread network coverage, untethered access to information, and support for mobility [26]. It allows utilities to avoid huge network cost and additional time for building a dedicated communications infrastructure [27]. It comes with huge potential benefits for the utilities, especially in third world countries whose are unable to install a smart meter for budgetary constraints. 2G, 2.5G, 3G, and LTE are the available cellular communication technologies in the market. According to the International Telecommunication Union and International Energy Agency, at present >95% of the world population is covered by the cellular network [28], whereas 83% has access to electricity from utility grid [29]. Indeed, most areas are covered by multiple cellular networks; thus it facilitates utilities to select the best cellular network available depending on location and maintain backup network capabilities. Accordingly, the cellular network can provide almost 100% network coverage for smart metering traffic with high reliability and flexibility.

As the services of cellular networks are shared by mobile users, it may result in network congestion and the quality of service of the network may be decreased. Therefore, it is crucial to maintaining the reliability of the smart meter traffic. SMS is a suitable option for the control and operation of the smart meter, especially for the third world countries where 3G and LTE networks have not been deployed yet. The most attractive feature of the SMS is its small latency time. The success rate of SMS transmission is nearly 100% if a dedicated server is deployed for a particular application. Thus, it can manage smart metering traffic within limited bandwidth with great reliability.

3 Background theory: energy measurement

A smart energy meter measures the amount of electrical energy supplied to the consumer in kilowatt hour (kWh) as well as real power, reactive power, apparent power, voltage, current, and frequency. Three parameters are required to calculate electrical energy – voltage, current, and power factor. These parameters are measured by the voltage sensor, current sensor, and zero crossing detector. In the market, there are some specific energy measurement chips with built-in energy measuring and power management system. They measure power by counting output frequency that is proportional to the time average value of the product of two voltage signals from voltage and current sensors [30]. However, these energy measuring chips are not flexible and not suitable for complex billing and tariff setting. The measuring techniques used in the USEM are described here.

Energy consumed by a load for a time interval T is given by

$$E = \int_0^T v(t)i(t)\,\mathrm{d}t = \int_0^T VI\,\sin(\omega t)\cos(\omega t - \theta) \qquad (1)$$

Since the digital processor cannot manipulate analogue data, direct implementation of (1) is not possible but sampled data can be manipulated. The analogue-to-digital converter (ADC) gives the analogue voltage and current in digital form. The accumulation of voltage ($V[n]$) and current ($I[n]$) samples over a time and then dividing the total accumulated value by the number of samples (N) gives real power P

$$P = \frac{\sum_{n=0}^{N-1}(V[n]I[n])}{N} \qquad (2)$$

where $V[n]$ and $I[n]$ are sampled voltage and current, respectively. Equation (2) does not have power factor term, i.e. cosine of the phase angle. The value of the phase angle is embedded in the voltage and current samples. Energy in terms of watt seconds can be obtained by

$$E = \frac{\sum_{n=0}^{N-1}(V[n]I[n])}{F_s} \qquad (3)$$

where F_s is the sampling frequency. The sampling frequency is calculated by

$$F_s = \frac{F_t}{(\mathrm{PER} + 1)} \qquad (4)$$

where PER is timer period register value and F_t is timer frequency.

As per Nyquist sampling theorem, the maximum frequency of the input signal should be less than or equal to half of the sampling rate (frequency). Energy metering specifications call for accurate measurement of frequency content up to the 20th harmonic which is 1 kHz on the 50 Hz line frequency. A Sampling frequency of at least 2–4 kHz is required. In this work, the sampling frequency is 4 kHz.

Apparent power can be calculated by multiplying the instantaneous voltage and instantaneous current. Power factor can be derived from dividing real power by the apparent power. So, all electrical measuring parameters are easily obtained using a microcontroller with sampled values of voltage and current without zero crossing detector.

The sequence of ADC sampling and accumulation is shown in Fig. 1. The microcontroller has an input voltage range of 0 to DC supply voltage (Vcc). Thus, sampled AC signal needs to be biased at Vcc/2. However, the DC bias voltage needs to be removed in order to calculate RMS voltage, current, power, and energy.

There are two approaches of removing dc bias; the high-pass filter and low-pass filter. The high-pass filter allows the high-frequency component through removing the bias, whereas the low-pass filter finds the bias at first and then subtracts the bias from the signal. The second approach is used in this work.

Moreover, the measuring technique requires zeroth-order finite impulse response (FIR) filter to compensate for the phase angle delay on current sample due to the ADC measurement.

A fractional delay introduced in voltage sample by the use of single zero-FIR filter is given by

$$y[n] = x[n] + \beta x[n-1]] \qquad (5)$$

Here x is input voltage sample, y is delayed output voltage sample, n is sampling sequence and β is delay gain.

Equation (5) in Z domain

$$Y(z) = X(z) + \beta z^{-1}X(Z) \qquad (6)$$

$$H(z) = \frac{Y(z)}{X(z)} = 1 + \beta z^{-1} \qquad (7)$$

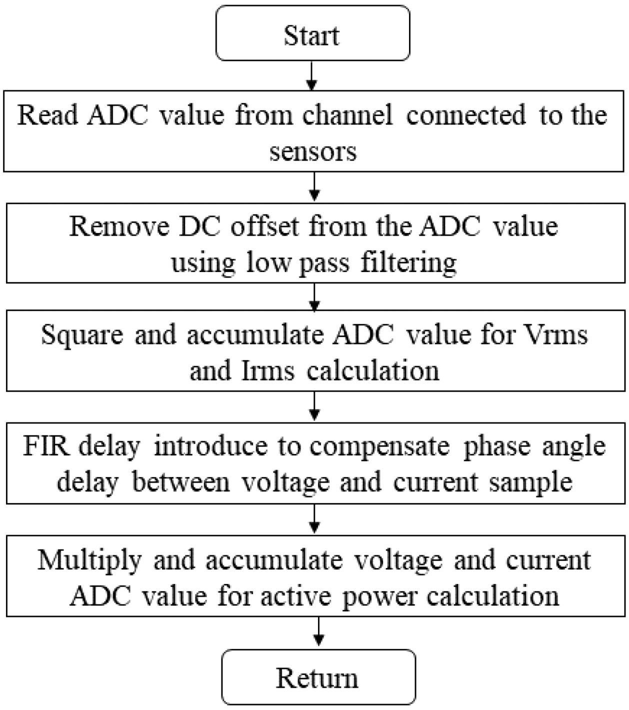

Fig. 1 *ADC sampling and accumulation sequence*

$$H(\mathrm{e}^{\mathrm{j}\omega}) = 1 + \beta\cos\omega - \mathrm{j}\beta\sin\omega \tag{8}$$

Amplitude and phase characteristics are analysed by the following expressions:

$$A(\omega) = \sqrt{1 + 2\beta\cos\omega + \beta^2} \tag{9}$$

$$\theta(\omega) = \arctan\frac{\beta\sin\omega}{1 + \beta\cos\omega} \tag{10}$$

where ω is angular frequency:

$$\omega = \frac{2\pi f}{F_\mathrm{s}} \tag{11}$$

Group delay can be calculated according to the following relation:

$$\tau_g = -\frac{\mathrm{d}\theta(\omega)}{\mathrm{d}\omega} = \frac{\beta(\beta + \cos\omega)}{1 + \beta^2 + 2\beta\cos\omega} \tag{12}$$

Equalieing the filter group delay with the inherent phase shift of the current transformer (CT), the parameters for the filter realisation are obtained as

$$\beta = -\frac{(1 - 2\tau_g)\cos\omega \pm [(1 - \tau_g)^2\cos^2\omega + 4\tau_g(1 - \tau_g)^{1/2}]}{2(1 - \tau_g)} \tag{13}$$

To compensate for the digital filter amplification, the output, i.e. $y[n]$, should be multiplied by inverse filter amplification A^{-1}. This parameter is calculated by

$$A^{-1} = (1 + 2\beta\cos\omega + \beta^2)^{1/2} \tag{14}$$

The filter coefficients β and A^{-1} are calculated during the phase angle correction calibration.

The discrete sample and accumulation for voltage calculation can be written as

$$V'[n] = V''[n] - Vdc_{\mathrm{offset}} \tag{15}$$

$$V[n] = A^{-1}(V'[n] + \beta V[n-1]) \tag{16}$$

$$\sum V^2 = \sum_{n=0}^{N-1}(V[n]V[n]) \tag{17}$$

where $V'[n]$ and $V''[n]$ are the sampled output voltage signal from ADC channel and low-pass filter, respectively.

Considering filter coefficient, V_{rms} and I_{rms} can be written as

$$V_{\mathrm{rms}} = K_v\sqrt{\frac{\sum_{n=0}^{N-1}(V[n]V[n])}{N}} \tag{18}$$

$$I_{\mathrm{rms}} = K_i\sqrt{\frac{\sum_{n=0}^{N-1}(I[n]I[n])}{N}} \tag{19}$$

where K_v and K_i are calibration constants to correct the measured values to obtain high accuracy.

Finally, P can be written as

$$\sum P^2 = \sum_{n=0}^{N-1}[(K_v V[n])(K_i I[n])] \tag{20}$$

$$P = K_v K_i\sqrt{\frac{\sum_{n=0}^{N-1}(V[n]I[n])}{N}} \tag{21}$$

Calibration constants K_v and K_i can be easily determined by trial and error technique comparing the voltage and current measurement with standard voltmeter and ammeter, respectively.

The energy is the measured active power accumulated over a period of time. The accumulated active power for 1 s is multiplied with 1 s to get the energy for 1 s. This watt–sec value is converted to kWh to get the energy in kWh. The kWh for every 1 s is being accumulated with the previous value to get the cumulative kWh.

4 Proposed USEM system

4.1 Complete system architecture

Proposed USEM system consists of three main terminals: user end, meter end, and authority end, which are shown in Fig. 2. Each part is authorised by its identification; user identification number (UIN), meter identification number (MIN), and authority identification number (AIN). AIN has built-in remote access to control and operate all functionalities in the USEM-DSLM option, tariff plan setting, payment mode switchover, connection–reconnection, UIN, and recharge centre setting. UIN has access only to getting meter information and remote meter switching, and MIN sends necessary confirmation SMS to AIN and/or UIN after every operation.

4.2 Metering architecture

The hardware of the USEM is simpler and cheaper than the conventional smart energy meter. Instead of using the costly energy measuring chip (ADE 7751 or similar type), we have developed measuring circuit employing CT, potential transformer (PT), ADC IC chip, Timer IC, ATmega2560 etc. We did not use voltage divider and shunt resistor circuits in the USEM due to power loss issue [31]. The block diagram of the single-phase USEM is shown in Fig. 3.

The input current and voltage are converted by CT and PT, respectively, to a suitable range and then they are applied directly to two-channel 12-bit ADC. After proper amplification, the amplified digital current and voltage signals are fed to microcontroller ATmega2560, which then integrates the products of voltage and current samples over time. The microcontroller calculates active power, reactive power, consumed energy, and power factor based on the voltage and current measurements. It updates the LCD driver to display the calculated energy, real power, power factor etc. ATmega2560 has 86 I/O pins [32], which facilitates a wide range of control of the USEM for different purposes. Here two CTs are used for measuring the main load

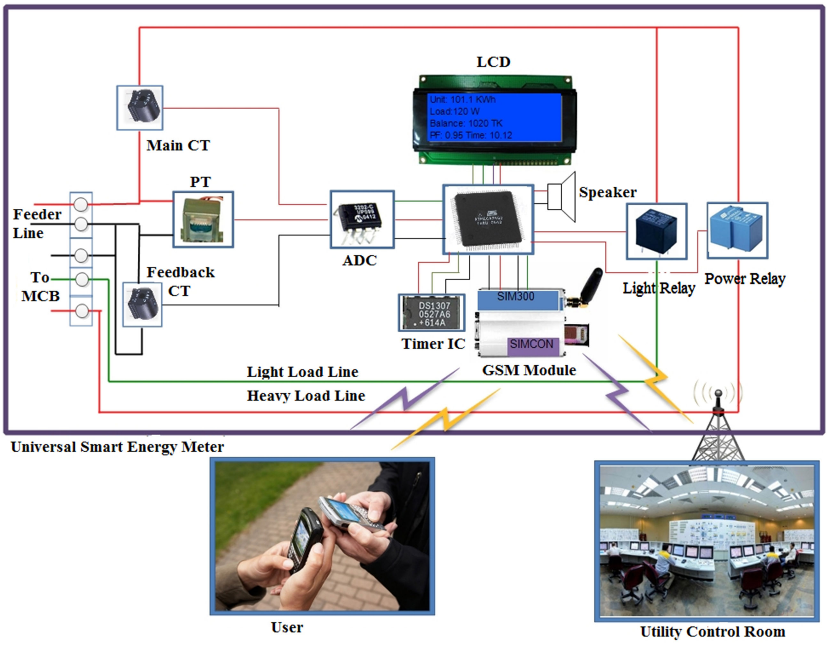

Fig. 2 *System model of proposed USEM*

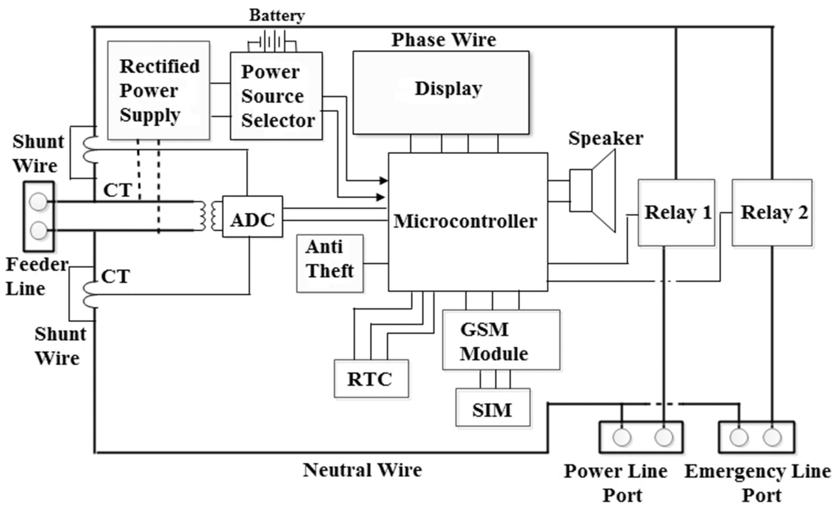

Fig. 3 *Block diagram of single-phase USEM*

current and feedback current with the aim of detecting meter tampering. Phase wire and neutral wire pass through the primary winding of CT. The maximum current rating of CT TA1309-200 is about 5 A [33], which can be extended using shunt wires of equal length having the same resistance. Real-time clock (RTC) is used for timely data storing in EEPROM, which helps to develop flexible tariff plan. The lithium-ion battery is used to run RTC during the event of a power cut. Power source selector selects power from the battery during power cut; otherwise, it selects power from supply main. Two relays are used for implementing numerous purposes such as switching the loads for DSLM operation, connection–reconnection for the unpaid bill, normal connection–reconnection of user and authority under the fault condition etc. Similar techniques could be applied in three-phase energy meters.

4.3 Demand-side load management

Integration of DSLM system with the USEM offers effective power utilisation as well as the emergency power supply during the power shortage, which can mitigate consumers' suffering during load shedding. The direct control method of high-power consuming loads such as refrigerator, air conditioner, water heater, and water pumps was shown in [34–36]. In the present study, SMS-based remote controllable DSLM is integrated with the USEM.

To accommodate remote load management system in the USEM, the electrical loads at a consumer's premises are divided into two types: heavy load and light load. The heavy load consists of the heater, motor, refrigerator, microwave oven, air conditioner, rice cooker, television etc. The light load consists of small wattage lamps and fans, which is termed as emergency load (EL). Under a feeder, the consumer must assign his/her EL and the information will be stored in the utility's server. During power shortage condition, an automatic feeder-wise calculation is done, and every consumer's EL is assigned according to the availability of power under the feeder at that time. From utility control room, permitted EL limit is sent by SMS to every MIN and the load limiting information is sent to the consumer via UIN. The DSLM algorithm of USEM is shown in Fig. 4.

After receiving authenticated EL limit SMS from AIN, USEM switches off the relay connected to the heavy load and then connects the permitted EL of the consumer. If the connected ELs are greater than the permitted ELs of the consumer, then buzzer gives beeps to reduce the ELs. After 30 s, the automated system shuts down the connected ELs and then EL relay is automatically switched ON to recheck the connected ELs after 30 s. If the connected ELs is less than or equal to permitted EL then the system runs normally with permitted ELs. Otherwise, the buzzer gives beeps and after 30 s the system again shut down the connected ELs. The check–recheck process continues three times.

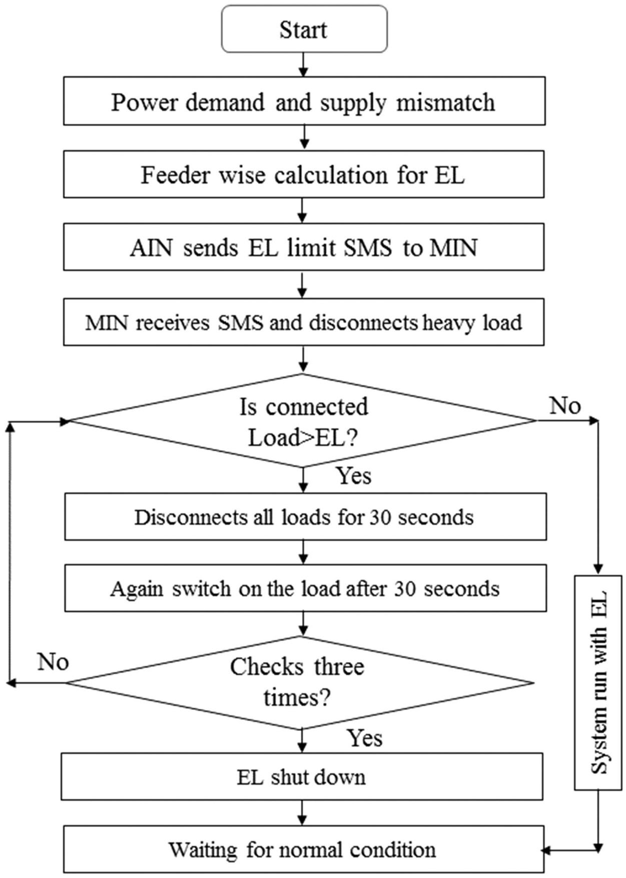

Fig. 4 *Flow diagram of DSLM system*

If the consumer does not adjust ELs within three times, his/her all loads are permanently shut down. In this situation, the consumer can use the permitted EL by sending an SMS to MIN after reducing the excess load. The EL limit condition can be switched back to normal mode by sending an SMS from utility control room to USEM when power supply becomes normal. A consumer cannot use the load more than the permitted ELs and there is no way of tampering the USEM device to use more load than the permitted EL because the load current is always monitored by CT.

Besides, USEM can also monitor permitted loads (PLs) of a consumer in the same method as ELs by measuring the load current. PLs are the maximum permissible loads that a consumer can normally use without paying extra fees of maximum demand. If a consumer tries to use a load more than PLs, then USEM will shut down the consumer's total load and inform consumer's status to the authority by sending SMS to the authority control room and then authority can take necessary actions.

4.4 Mode switching and flexible tariff setting

Every operation of the USEM such as remote connection–reconnection, payment mode selection, and tariff plan configuration can be controlled from authority end and/or consumer end. The salient features of the USEM are remote mode switching and tariff plan setting. The USEM can be setup as prepaid or postpaid mode simply by sending an SMS from authority with specific SMS code without changing any hardware or software. It also has wide flexibility and versatility in tariff plan setting (block rate, TOU, and the combination of both). All tariff plans can be configured by SMS from utility control room. It should be noted that a combination of block rate and TOU tariff does not exist in many third world countries. To set different tariff plans in USEM, there are different authorised SMS codes. All tariff spans can be divided into any value into three different plans.

4.5 Recharging system

Flexible recharging system makes the smart meter more convenient and plays a crucial role in DSLM [37]. Recharging in the existing metering system is not versatile. For example, in [16], recharging was done by online credit card or online banking transaction. The main limitation of this work is the unavailability of online credit card system and online banking system facility for all consumers. The recharging system of the USEM is simple, flexible, and versatile as it does not require dedicated vending station. The recharging can be done from a variety of existing financial payment systems applicable for mobile recharging.

At first, the consumer sends a request to the utility server from his personal account by SMS, where the personal account is connected to consumer's payment account like mobile balance, online banking account, credit card etc. Then the utility server sends an authentication SMS to USEM, and after completing successful recharge, the consumer gets a confirmation SMS.

4.6 Bill calculation

Flow chart of the USEM recharging system for prepaid and postpaid modes is shown in Fig. 5. The mode of operation can be selected remotely from utility server using the microcontroller. For postpaid metering, the proposed system supports negative balance within specific date assigned by authority. The microcontroller checks present balance after *n*th day of every month and then billing status is sent to a user using UIN mentioning the deadline for bill payment. After the deadline, the microcontroller again rechecks the present balance and then makes a decision. If recharging is done within the specific date, then meter works normally; otherwise, the meter will be disconnected automatically with alarm.

For further reconnection, administrative permission is required with a penalty. In the case of prepaid mode, when the present balance is greater than XX (depends on system utility authority), the meter operates normally; if not, the system sends an SMS to the consumer asking to recharge the balance and permits to use up to YY balance, where YY is less than XX. If recharging is done, then the system runs normally; if not, after exceeding YY balance limit, the supply will be automatically disconnected. The consumer can get reconnected at any time through recharging.

4.7 Protection scheme

Protection schemes against unlawful utilisation of electricity, e.g. meter bypassing, neutral line disconnection, and tampering, are available in USEM. In the case of neutral line disconnection/partial bypass, protection is given by comparing phase current and neutral current using two CTs. If both measurements are not equal, then partial bypass is detected. In the case of complete bypassing, the PT in USEM measures voltage and sends an SMS to AIN informing powerless status when there is no voltage found at the PT. If the authority confirms that power supply is available to the consumer, then the authority takes necessary steps. For meter tampering protection, optical detection technique is employed using light-dependent resistors. Also, meter cover contact with the meter body would be disconnected when the cover is opened, and this disconnection is easily detectable using the ground pin and the interrupt pin of the microcontroller. When tampering is detected, USEM disconnects the load and informs the authority by sending SMS. Moreover, the USEM can protect the home appliances in case of over voltage, under voltage, and overload. The voltage and current are always monitored. If the voltage/current goes below or beyond the certain value set by the utility, the smart energy meter shuts down the consumer's load and informs authority and the consumer.

4.8 Monitoring and notification system

USEM not only detects under voltage, over voltage, and over current but also gives protection against these faults and notifies the authority. This type of monitoring and protection system provides additional household protection. Authority can monitor

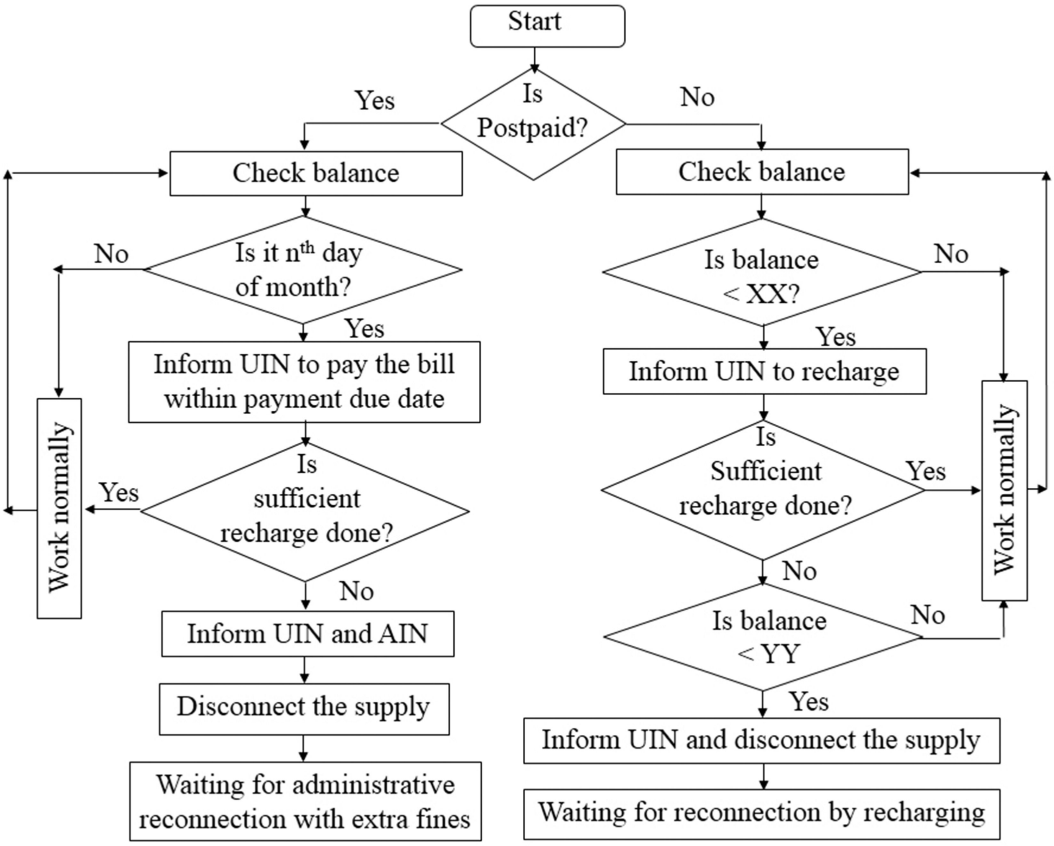

Fig. 5 *Flow chart of the USEM recharging system for prepaid and postpaid modes*

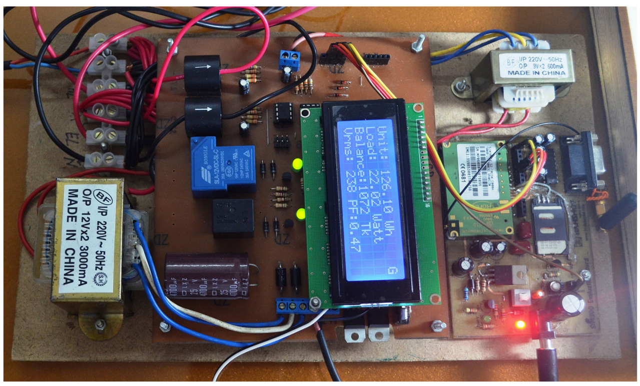

Fig. 6 *Implemented USEM device*

the status of every consumer from the utility server and all necessary information like billing information, last date of payment, meter status, load shedding notification, and device notification can be received via SMS.

5 Performance of USEM

The implemented USEM device is shown in Fig. 6, which displays consumed energy, connected load, remaining balance, power factor, and system voltage.

We have tested the implemented USEM for different resistive, inductive, and capacitive loads. The results shown in Table 1 demonstrate that the accuracy level of the developed USEM is very high.

The implemented USEM is perfectly calibrated for its normal operating range. The measurement accuracy and all features of the USEM are tested with various loads with a wide range of voltage and current. All quantities are compared with standard calibration meter Fluke 5502A. We have measured the voltage from 150 to 300 V with USEM and compared it with the Fluke 5502A, which is shown in Fig. 7*a*. It shows that the USEM gives a small error when the operating voltage is <180 and >240 V.

We have also compared the current measurement between the implemented USEM and the standard calibration meter Fluke 5502A. The result is shown in Fig. 7*b*. It shows that the current measurement gives a small error when the operating current is <0.2 A and >15 A.

Fig. 8 illustrates some key operations of the USEM: mode switching, remote tariff plan setting, recharging, remote status checking, and tampering protection. In every operation, control SMS is sent from AIN, and MIN receives control SMS from authenticated number, and after the command, execution authority gets confirmation SMS. For tampering of the meter, authority gets tampering alert after disconnecting the load.

We have used specific SMS formats for different operations of the USEM. The USEM sends notification SMS to the consumer by sending billing information, disconnection notification with

Table 1 Comparison of the results obtained from USEM and standard meters

Load type	USEM				Standard meter (Fluke)				% Error
	V volts	IA	P.F.	PW	V volts	IA	P.F.W	PW	
60 W, incandescent	242	0.27	1.00	65.34	242	0.27	1.00	65.34	0.00
100 W, incandescent	240	0.45	1.00	108	240	0.45	1.00	108	0.00
200 W, incandescent	240	0.91	1.00	218.4	240	0.91	1.00	218.4	0.00
40 W, fluorescent	238	0.22	0.83	43.46	238	0.22	0.832	43.56	−0.23
32 W, CFL	238	0.25	0.58	34.51	238	0.25	0.584	33.92	−0.69

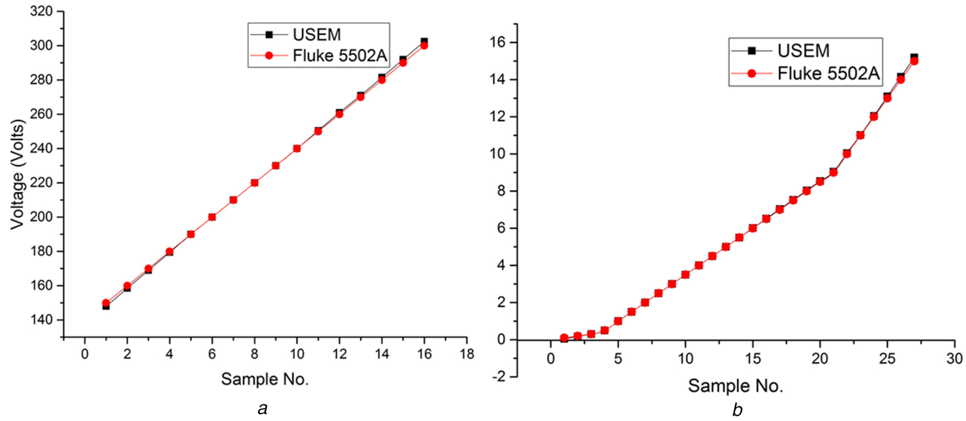

Fig. 7 *Measurement comparison with the USEM and standard calibration meter Fluke 5502A*
(a) Voltage, ***(b)*** Current

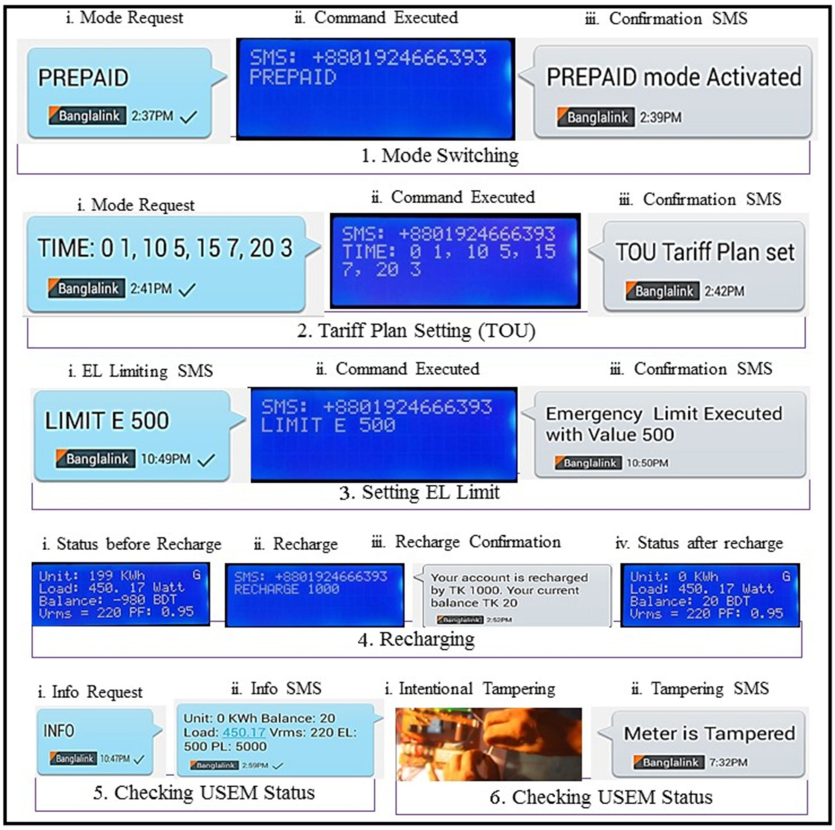

Fig. 8 *Execution of some key operations in the USEM*

explanations, EL and PL load limit setting information etc. Also, the authority gets notification SMS from the USEM when a consumer violates company's rules and regulations, tampers meter, consumes power with low power factor etc.

For demonstration purpose, the real payment server using banking and credit card transaction has not been implemented; rather SMS-based recharging and balance adjustment are implemented here. Temperature influence on measurement, measurement's accuracy with different frequencies, and electromagnetic compatibility testing were not discussed in detail in this work as its scope is the implementation of a working prototype of low-cost universal smart energy metering using an existing cellular network.

6 Conclusion

In this work, a USEM is proposed, designed, and practically implemented in the laboratory with a view to configuring prepaid as well as postpaid mode. The meter has DSLM option as well as automatic monitoring and protection system with a wide extent of flexibility and versatility in addition to all features of commercially available smart energy meters. The DSLM mode can be configured by SMS for PL limit and EL limit conditions, which leads to having complete blackout-free power system during the shortage of electric power. Compared to the conventional energy meter, the recharging system of USEM is cost effective, attractive, and very simple. The USEM has flexible tariff plan setting that can be configured and reconfigured remotely simply by SMS. It also provides additional features, such as remote power disconnection, power reconnection, power disconnection alert and tampering alert, which could reduce a great amount of technical and non-technical losses as well as manpower. The total implementation cost of the USEM is about $40 USD, which is well below the cost of the smart energy meters available in the market (Oncor Electric Delivery, TX, USA charges $2.19 USD per month for 10 years with a cumulative cost of $262.8 USD). Moreover, the prototype of USEM has great academic value for further research in direct and indirect load managements, remote software update, cellular-based control system etc.

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