Design and Study of a GSM Smart Energy Meter to Reduce Load-shedding and Cost of Energy

Jehanzeb Ahmad, Tahir Nadeem Malik, and Bilal Ashraf Awan

***Abstract*—** Pakistan is facing a crippling energy crises with load shedding of around 12 hours per day during peak summer months as electricity demand far exceeds supply. This paper presents the design of a special GSM based smart meter to reduce the load shedding significantly while at the same time, saving energy and costs. Instead of cutting of complete power as is done presently during load shedding, the smart meter continues to provide an emergency power to a premises. A comparison is done with the common alternative of using a UPS with battery to supply the same amount of emergency power. The losses resulting from the inefficiency of the inverter, and the loss of conversion from 220V to 12V for battery charging has been calculated through experimental data, and the cost of battery replacement based on battery lifetime prediction analytic models developed already, has been estimated. The paper shows that by using a simple smart energy meter significant reduction in losses can be achieved while at the same time cost of energy is reduced for the end consumer and a more convenient solution to load-shedding can be provided.

***Keywords*—**Depth of Discharge (DOD), Global system for Mobile (GSM), inverter, smart meter, Kilo Watt-hours (KW-hrs), lead Acid battery, State of Charge (SOC), Uninterrupted power supply (UPS)

I. Introduction

IN Pakistan, the peak electricity demand occurs during summer and is around 19000 MWs and the peak generation is around 14000 MWs resulting in a net deficit of 5000 MWs.[1]. The Government run utility has to resort to load shedding to reduce demand. The continuous duration of load shedding is one hour and there is 06 to 12 hours of load shedding in a day depending on the gap between supply and demand. All cities are divided into small zones, and power to a complete zone is turned off during load shedding. Due to this, even hospitals, emergency services, traffic lights, street lights and other essential services falling in that zone are disrupted. This causes a great deal of inconvenience for the residents of that area in addition to being a security hazard. . For comparison purposes in this paper the average duration of load shedding for a zone has been taken as 06 hours in a day lasting 01 hour maximum at a stretch. The cost of electricity is taken as 18 Cents / KW-hr. Most of the residential and commercial consumers have installed 1 KW inverters/UPS with lead acid batteries to supply emergency power during the load shedding hours.

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II. GSM Network In Pakistan

Pakistan has a highly advanced mobile network infrastructure with GSM coverage of almost all its geographical area. There are close to 129 Million mobile phone users in the country [2]. There are 05 major mobile operators providing services with overlapping cell areas. The mobile service is cheap and very reliable. In addition all mobile operators have excess installed capacity. The mobile network continues to work during load shedding as all mobile operators have installed diesel generating sets to provide backup power.

This paper presents a solution to load shedding by using the existing GSM infrastructure available in the country. A small power management module connected with the consumer energy meter with the capability of communicating through GSM can save the consumers and the utility millions of dollars annually which are wasted due to the inefficiency of the batteries and inverters.

III. Smart Energy Meter Design

A smart energy management module connected to the output of the energy meter with GSM based communication facility manages the load of the consumer during peak demand time. The module has two outputs as shown in fig. 1. The first output is for full load of the consumer and is normally enabled. During load shedding, instead of cutting off the power of a complete area, the utility company sends a data packet using GSM to all meters in a specific zone or in a cell. On receiving this packet, the energy management module cuts off power to the first output and supplies power through the output No. 2 only which is for emergency load of the consumer. The maximum limit of the emergency load can be set by the utility and the consumer can be informed through a consumer user interface. Since most consumers in Pakistan have installed 1 KVA inverters, therefore for the purpose of

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calculations, the emergency load capacity has been set at 1 KVA. All savings resulting from this scheme would be based on a 1 KVA load for 06 hours per day.

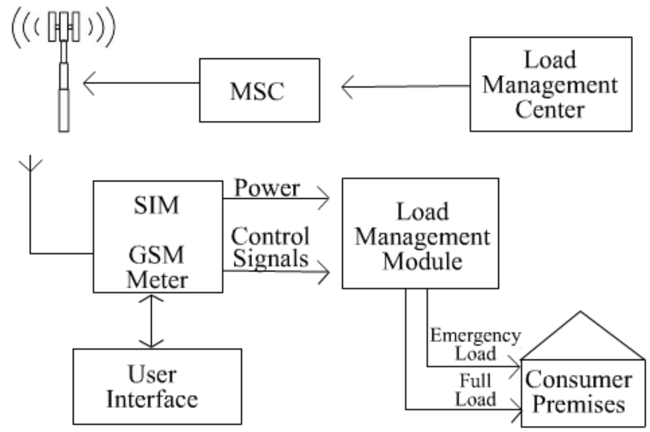

Fig. 1 Design of Smart Energy Meter using GSM Network

The smart energy management module as shown in Fig. 1. will continue to provide emergency power during load shedding and thus save the consumer the capital cost of buying and maintaining an inverter and batteries and would save additional energy by eliminating the losses of the inverter, charger, and batteries. The module would also save energy for the utility as with the current system, the utility has to supply additional power during normal hours to charge the battery and make up for the conversion losses of the inverter-battery system. The system would also save the replacement cost of the battery. In the next section, the net losses of the complete inverter-battery system have been calculated.

IV. Efficiency Calculations

A typical user installation of an inverter-battery system is shown in fig. 2.

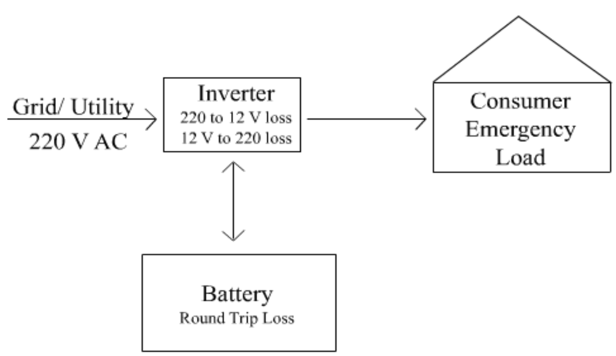

Fig. 2 Typical Consumer Premises Setup for supply 1 KVA load.

The system incurs the following losses:

- Battery efficiency and lifetime replacement costs
- Conversion of 12V DC to 220V AC by the inverter
- Conversion of 220V AC to 12 V DC for charging of battery by the inverter
- Standby losses of the system

All these losses have been calculated and are presented below:-

A. *Battery efficiency and lifetime calculation*

There are two costs associated with using lead acid batteries:-

i. Round trip efficiency
ii. Replacement cost

1) Round trip efficiency

Round trip efficiency is defined as the ratio of the energy taken by the battery during charging and the energy supplied by the battery during discharging. There are I^2R losses in both the cycles and need to be estimated to find the round trip efficiency. In [3] a model for calculating the round trip efficiency of the battery has been presented. The round trip efficiency depends on a number of factors, the most important being the SOC of the battery and the charge / discharge current. The chief losses in the battery both during charging and discharging are the internal I^2R losses. The efficiency for charge and discharge cycle has a range of 80% to 99% depending on the SOC of the battery [3]. For calculating round trip efficiency, a 50% SOC of the battery has been assumed for charging and an 80% SOC has been assumed for discharging. From the model presented in [3], the round trip efficiency comes out to be

Efficiency of charging at 50% SOC = 90%
Efficiency of discharging at 80% SOC = 96%
Total Round trip efficiency of the battery = 90 % X 96% = 86.4 %. (1)

2) Replacement cost

The replacement cost of a battery depends on its initial cost and the total amount of energy a battery can supply during its lifetime. A market survey in the city of Islamabad, Pakistan was conducted to get an initial cost estimate in the month of December 2013. Following were the results of the survey based on average price of the batteries from various vendors.

Table I
These prices are for common lead acid batteries.

Battery Amp-Hrs at 12V	Battery Capacity in KW-hrs	Battery Cost in US $	Cost / KW-hrs in US$
50	0.6	39	65
70	0.84	44	52.3
100	1.2	68	56
150	1.8	100	55
200	2.4	125	52

It is evident from the survey that larger capacity batteries tend to be cheaper in terms of cost per watt. For our calculations we have chosen a Lead Acid 12V, 200 Amp-hr battery with an initial cost of US$125.

A number of analytic models [4] have been presented in the literature for predicting the lifetime of a lead acid battery. The lifetime of the battery depends on a number of factors, but the most important ones are DOD (Depth of discharge) and battery SOC (State of charge). In addition charging rate, over charging, loss of water all affect the lifetime of the battery. Generally the more deeply a battery is discharged in each discharge cycle the shorter its lifetime would be.[4]

A review of manufacturer data sheet in [5] shows that the number of cycles of a battery is dependent upon its depth of discharge and varies between 400 cycles for 80% DOD and up to 1500 cycles for 30% DOD for a AGM deep cycle battery. For lead acid batteries mainly used in cars, the number of cycles are much less, specially when used with inverters where they are deeply discharged every time.

In [6] a simple approximate design equation for estimating battery lifetime has been presented. Based on this equation, battery lifetime is given as

$$T = (329.9/E) \times S \quad (2)$$

Where
T= battery lifetime in years
E = annual energy discharged from the battery
S= Size of the battery in Amp-hrs.
Due to its relative simplicity for estimating the lifetime, (2) will be used for the calculations. Based on the previous assumptions the lifetime of the battery is calculated as under:-

Energy supplied by the battery in one hour load-shedding
= 1 KW-hr
Energy supplied per day based on 06 hours of load-shedding
= 6 KW-hrs

Annual KW-hrs supplied by the battery
(E) = 365 X 6 = 2190 KW-hrs

Battery Capacity (S) = 200 Amp-hrs
Using (2), T = (329.9 /2190)X 2.4 = 0.36 years
= 4.3 months (3)

Total KW-hrs supplied by the battery during its lifetime
= 4.3 X 30 X 6 = 780 KW-hrs
Cost of the battery = US$ 150
The Per KW-hr replacement cost of the battery using (3)
= 150 / 780 = 19 Cents / KW-hr.

With round trip efficiency of 86%, the input power to the battery would be 780 / .86 = 906.9 KW-hr

Cost per KW-hr of round trip efficiency loss = (906.9 – 780)
= 126.9 X 18 Cents / KW-hr = $22.8
Cost per KW-hr = 22.8 / 780 = 2.9 cents

Total cost of battery efficiency and replacement = 2.9 + 19
= 21.9 cents / kW-hr (4)
As calculated from (4), just the battery cost is more than the cost of the electricity per KW-hr supplied by the utility.

B. *Conversion loss of inverter from 12 V DC to 220V AC*

For estimating the conversion loss from 12V to 220V, a commonly available Inverter manufactured by Inverex Inc, Model number QAUNTUM 1200, 1.2 KVA buck-boost type has been used to empirically calculate the losses. The efficiency reported by manufacturers is usually much higher and is for ideal scenarios. The actual efficiency is much lower, hence the authors of this paper decided to setup a small experiment with variable load to measure the conversion efficiency.. The efficiency of the inverter depends on the load applied on it. For low loads the efficiency is lower and it increases as load increases. Purely resistive loads were chosen for the calculations in order to simplify the power calculations.
Actual measurements taken for the inverter when supplying 220 V load are as follows:-

TABLE II
INVERTER EFFICIENCY DURING CONVERSION FROM 12V TO 220V

Input current (A) at 12 V	Input power (W)	Output voltage (V)	Output current (A)	Output power (W)	Efficiency %age
6	72	240	0	0	0
15.8	189.6	238	.4	95.2	50
26.4	316.8	236	.9	212.4	67
38.5	462	232	1.4	324.8	70
58.8	705.6	232	2.1	487.2	69
70.8	849.6	230	2.5	575	67
82.8	993.6	230	3.0	690	69

As can be seen that even under no load conditions the inverter consumes 72 Watts of power. The efficiency is lower for smaller loads, however the maximum efficiency reached is only 70% under various load conditions, which is much less than reported by manufacturers.

For the charging efficiency the following measurements were recorded for same model inverter.

TABLE 3
READINGS OF CHARGING EFFICIENCY OF THE INVERTER

Charging current (A)	Charging voltage (V)	Charging power (W)	Input current (A)	Input power (W)	%age Efficie-ncy
.2	13.6	2.72	.1	22	12
3.7	12	44.4	.8	176	25
6.8	12	81.6	1.1	242	33
16.3	12	195.6	1.6	352	55
23	12	276	1.6	352	78

The best efficiency during charging is reached at a high charging current of 23A and is around 78%.

Round trip efficiency of the inverter (charging then discharging) = 78% X 70% = 54.6%

Cost of a KW-hr through an inverter = Utility cost / .546
= 18 / .546 = 32.96 cents / KW-hr
Increase in cost = 32.96 – 18 = 14.9 cents / KW-hr

V. FINAL RESULTS

The final increase in cost for the entire system is given as Replacement cost of battery plus round trip loss in battery plus round trip loss in inverter. All these quantities in terms of KW-hrs were calculated. Based on the values obtained earlier the total extra cost of the UPS and battery system comes out to be

36.8 cents / KW-hr. Hence by using an inverter-battery system an additional 36.8 cents are added to utility rate of 18 cents per KW-hr. This is an increase of nearly 200%.

Annual extra cost incurred by a consumer with 06 hours of load shedding and 1KVA emergency load comes out to be US$ 800. This is large enough to justify the initial cost of a GSM meter at the premises, not to mention the convenience of having all emergency services like traffic lights, hospitals, street lights working even during load-shedding.

1) Loss to Utility

Since the entire energy required to charge the battery through the inverter during normal grid hours is provided by the utility, so we can calculate based on the efficiency of the battery and inverter, as to how many extra units of electricity are supplied by the utility to provide emergency load of 1 KVA. Based on the calculated done earlier the entire system efficiency comes out to 46%. (Efficiency of the system = battery RT efficiency X inverter RT efficiency = 86.4 X 54.6 = 46 %)

Therefore the utility has to supply 2173 watts so that the end consumer can get 1000 watts from the system. This roughly comes to 6 extra units of electricity per day and 2190 units per year per consumer. The utility can save a huge amount of electricity per year by installing a smart meter to provide 1KW of emergency load.

VI. CONCLUSION

In this paper, yearly loss to the consumer and savings by utility have been calculated using 18 cents / unit of electricity rate by using a GSM smart meter system. The Electric Utility in Pakistan can save around 2200 KW-hrs per consumer annually and the customer can save around $800 annually by using the GSM smart meter. This is a win-win scenario for both the consumer and the utility and can significantly reduce load-shedding in Pakistan.

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