# Smart Meter Assisted Electric Energy Management Schemes for Power Distribution and Residential Customer Usage

[1]Sujan Chandra Sarker, [2]Md. Arif, [3]Abinash Chakma, [4]Uttam Kumer Roy and [5]Raqibul Mostafa
*Dept. of EEE, United International University, Dhaka, Bangladesh*
Email:[5]*rmostafa@eee.uiu.ac.bd*, {[1]ecube7sujan, [2]*arif.uiu09*, [3]*abinashchakma*, [4]*uttam093}@gmail.com*

***Abstract***−**Smart meter, the core part of smart grid system, is becoming an active field of research for its immense potential in efficient power distribution and load management. It is expected to have potential applications in Bangladesh as well. Efforts are already underway from distribution companies to introduce intelligence in the meter system. This paper proposes several smart meter assisted economic energy consumption schemes for consumers and power outage reduction scheme for distribution utility companies that will enhance the quality of service. Necessary analyses have been included to verify the proposed schemes. Real-life electric power demand and supply data from various substations under Dhaka Electric Supply Company (DESCO) have been used to validate the power outage reduction scheme. Results show that the schemes provide economic benefit to the consumer and an effective load management strategy for distribution companies. Operating issues related to the proposed schemes have also been detailed to highlight the practicality of the proposed schemes.**

***Keywords-Smart meters, power management, power outage reduction, implementation factors***

## I. INTRODUCTION

Smart grid is being increasingly seen as an efficient and effective power transmission and distribution system. Smart meters at customer premises represent the core part of the intelligence and automatic control system of smart grid infrastructure [1]-[2]. Smart meters present themselves as enablers for cost-effective energy management strategies for consumers and power distribution companies [3]-[4]. An estimated 62% Bangladeshi people is connected to the electric grid. The electricity supply is not reliable and peak demand cannot be met. In the rural areas, where more than 70% of the population lives, only about 30% of them have access to electricity supply [5]. In the context of energy scenario in Bangladesh where there is a large deficit between energy generation and demand, smart meters offer the potential of providing economic usage of energy for customers and smart management of distribution system so as to minimize the impact of the energy deficit [6]. Dhaka Electric Supply Company (DESCO) in an attempt to introduce intelligent metering keeping in line with smart meter concept conducted a pilot project to introduce pre-paid meters with limited feature for residential customers. Extension of such approaches will form the future of electric power distribution and consumption strategies by relying on smart meters with advanced algorithms and reliable two-way communications between the meter and the central control located at the distribution center. With increase in energy tariff coupled with energy deficit, customers will look for avenues to reduce their electricity expenses while expecting a good quality of service from the distribution companies. With a smart meter installed at the customer premise, customers can avail various options to optimize electricity usage and minimize energy expense.

This paper proposes several energy management strategies that are applicable at customer and distributor end. This includes keeping the monthly bill within a pre-set limit and being notified of tariff slabs as energy is being consumed. The proposed techniques further include energy consumption within the assigned load limit or sanctioned load. Additionally, it is possible through implementation of the proposed techniques to alleviate the existing power outage crisis and to provide uninterrupted power at a useful level. It may be worthwhile to draw differences with research that address smart meter applications at customer premises [3]-[4] and [6]. The cited research focuses on actual hardware details of a household smart meter, wider range demand side management or configuration of appliances to match the peak-hour in demand. In contrast, the research presented in this paper provides an in-depth analysis of load management scheme and addresses the practical issues that arise from such schemes. Moreover, the proposed schemes have the potential of mutually reinforcing the efficacy of load management technique. Recorded data of supply and demand over time from DESCO has been used to analyze the performance of the proposed power outage reduction scheme [7]. It is expected that the research presented in this paper will provide a practical direction for technically and economically feasible deployment.

The organization of the paper is as follows. Section II presents smart meter enabled smart electricity consumption management for customers. Section III proposes power outage reduction scheme while Section IV addresses practical issues related to the proposed management schemes. Section V touches upon the communications infrastructure to support the proposed schemes followed by concluding remarks.

## II. SMART METER FOR ECONOMIC ENERGY USAGE

Consumers can regulate his/her energy usage through smart meter based usage management: (A) Fixed budget for electric bill. (B) Electricity cost management according to price slabs, and (C) Sanctioned load monitoring. These are described in details in the following subsections.

### *A. Fixed budget for electric bill*

A smart meter can be used to help the consumer plan a monthly budget for electricity usage. The consumer will give his/her allocated budget as an input to the meter and the meter will calculate the available energy units based on the existing tariff rate. Based on the available units, the meter will calculate the daily average allowed unit. For each day, the meter will determine the consumed energy units for that day and raise an alarm if that consumed energy is higher than the average value. Thus, the consumer will be informed of his/her daily status on consumed energy units and will adjust the energy consumption for the remaining days of the month so that the total consumed energy is within the allotted budget set at the beginning of the month. An example of variation of daily consumed energy is shown in Figure 1 along with the meter computed the average daily energy unit. Here it is assumed that the allocated budget allows 570 units (i.e., kW-Hr) of energy for a given month and the resulting per day allowable energy use is about 18.8 units. Thus, whenever the consumed load exceeds the preset average value, the smart meter will raise an alarm and generate a message about exceeding the average and the remaining allowable energy units. The customer then lowers the energy consumption below the allowable daily limit

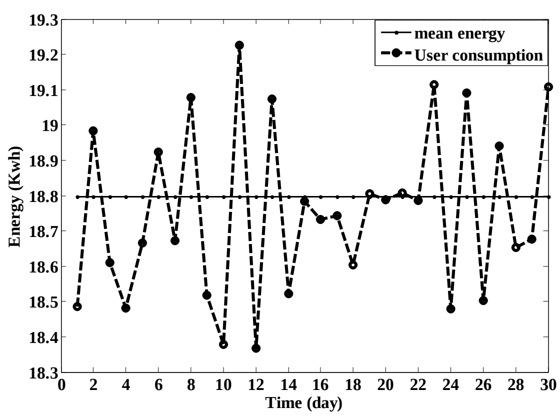


Figure 1: Energy consumption pattern following fixed budget plan.

Figure 2 shows the cumulative energy consumption from the budgeted limit (straight line representing mean energy) and from smart meter assisted user regulated scheme. The plots reveal that the proposed scheme enables the user to closely approximate the preset limit and to keep within the budget.

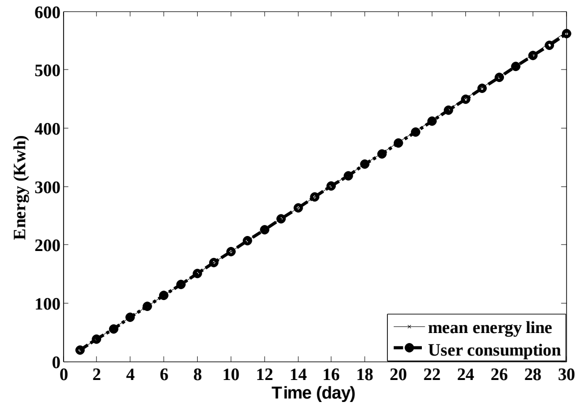


Figure 2: Allocated and daily energy consumption lines for a month.

### *B. Electricity cost management according to price slabs*

Dhaka electric supply company (DESCO) has implemented new tariff rates from 01 September 2012 in accordance with Bangladesh Energy Regulatory Commission (BERC) [7]. Figure 3 shows only the residential component of the tariff structure. This tariff rate is flat throughput the day irrespective of the peak demand hours.

| Customer Category | | Per Unit Rate (Tk.) |
|---|---|---|
| Category-A : Residential | | |
| a. | First Step : From 0 to 75 units | 3.33 |
| b. | Second Step : From 76 to 200 units | 4.73 |
| c. | Third Step : From 201 to 300 units | 4.83 |
| d. | Fourth Step: From 301 to 400 units | 4.93 |
| e. | Fifth Step: From 401 to 600 units | 7.98 |
| f. | Sixth Step: Above 600 units | 9.38 |

Figure 3: Price slabs for residential area in Bangladesh [5]

As per this tariff structure, the consumer pays increasingly higher tariff as his energy consumption increases and crosses over to the higher price slabs. A smart meter can help customers become more energy-conscious as it can alert them when the energy consumption is approaching the slab with the next higher tariff rate. This will help the customers to keep the energy consumption within an affordable limit. Various algorithms can be devised to keep track of the energy consumption, the related total cost and to implement the user control (manual or automatic).

### *C. Sanctioned load monitoring*

The customers of power distribution companies are assigned various levels of allowable sanctioned loads based on their demands whenever they subscribe to a particular company. The sanctioned load implies a tacit agreement that customer will not cross the sanctioned load. However, there is no provision for monitoring operating customer loads and penalty for exceeding the sanctioned load. Only recently, DESCO is deploying energy meters on a small scale with instantaneous load monitoring capability and applying penalty in case of exceeding the limit. That monitoring scheme turns off the meter should there be a first-time violation of sanctioned load and the user can turn on the meter. If the violation occurs second time, the user is still allowed to turn the meter on; however, with the next violation, the meter turns off and cannot be turned on except from official intervention along with a penalty. A better and more customer-friendly approach can be adopted where the meter will alert the consumer whenever the current load limit is within a certain percentage of the sanctioned load (e.g., within 5% or if the operating load is around 950W when the sanctioned load is 1kW). Thus, with this alert in mind, the consumer will plan his energy consumption and prioritize appliances so that overall load is kept below the sanctioned load. For the case when the operating load does exceed the sanctioned limit, then the smart meter will turn off and will not turn back on until the operating load is reduced below the sanctioned load limit.

### *D. Operational Aspects*

Hardware implementation of smart meter based energy management is an important operational aspect [8]. The proposed schemes (A-C) can be implemented through a smart meter, user interface and supporting communication system installed within consumer premises. For tracking energy consumption cost management (schemes A, B), a smart meter can be programmed to monitor daily usage and generate alert messages and alarms as needed. For implementing sanctioned load monitoring (C), the smart meter can play the role of load monitoring and generating alert messages and alarms. However, for consumer responses to the alerts and alarms, some additional features can be provided through indoor short range communication link between the smart meter and the appliances that can be controlled by the smart meter. It can be safely assumed that high-wattage appliances have major impact on operating load, pushing energy cost into higher price slabs. Thus, if the electrical outlets for these appliances are fitted with switches or relays (smart switches) controlled by smart meters through Zigbee based communication links, the operation of these devices can be controlled as per requirements from sanctioned load settings and tariff structures. For example, if the consumer would like to turn on a high-power appliance, he/she will press the smart switch and the smart switch will request the smart meter to enable it. The smart meter will monitor the parameter settings for a particular application (i.e., sanctioned load monitoring or energy cost reduction), will issue a command accordingly to the smart switch. For sanctioned load monitoring, the smart meter will not enable the smart switch till the load is reduced below the sanctioned limit. For energy cost reduction, the smart meter will disable the switch when an alert condition is encountered; however, the user can press the smart switch second time that will enable that switch and turn on the appliance.

## III. Power Outage Reduction

There is an acute shortage of electricity production at the national level in Bangladesh and the gap between production and demand has to be compensated by power outage. In the metropolitan areas, the power outage is usually scheduled by the electricity distribution companies where an alternating hourly pattern of availability of electricity and power outage (termed load shedding) is maintained. The outage scenarios in rural areas is even worse as generated electricity is mainly channeled to city and industry areas giving less priority to rural areas. A typical hourly pattern for electricity supply, demand and the resulting amount of load shedding for a specific zone (Dhanmondi zone under DESCO) is shown in Figure 4. From the figure it can be seen that the demand is higher than the supply throughout the day with the peak demand occurring at 5 pm onwards. The peak amount of load shedding is somewhat higher than 15 MW while the peak available supply is about 22 MW.

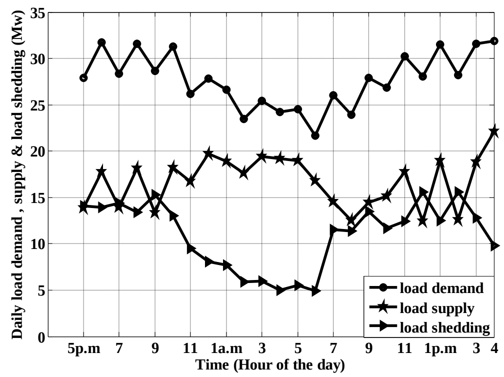


Figure 4: Load demand, supply and load shedding patterns of Dhanmondi zone in a metropolitan city Dhaka [1]

### *A. Proposed load management scheme*

As per the current practice of load shedding, the 11 KV feeders coming out of a substation are selectively switched off in a pre-determined schedule. Thus, a group of consumers belonging to a set of feeders faces power outage in specific one hour duration while in the next hour the feeders are switched on. Thus, there is an hourly "on-off" pattern for available electricity to the consumers. The consumers usually respond to power outages by installing IPS for home use and diesel generators for high-rise residential apartments and offices and educational institutes.

Smart meters in combination with appropriate control mechanism at the distribution substation side can enable an alternative strategy where electricity can be made available to the consumers throughout the day albeit at a reduced level. The distribution companies will predict the load demand D(t) at a given time t for a given day and will estimate a "load meet" factor *LM(t)*based on the available electricity supply S(t) allotted to it from the national grid as follows

$$LM(t) = \frac{S(t)}{D(t)} \qquad (1)$$

The central control system at the distribution substation will then relay this value to the smart meters for individual consumers and instruct the smart meters to reduce to a level as per the computed value of LM(t). A plot of LM(t) for the hourly patterns of demand and supply from figure 4 is shown in Figure 5.

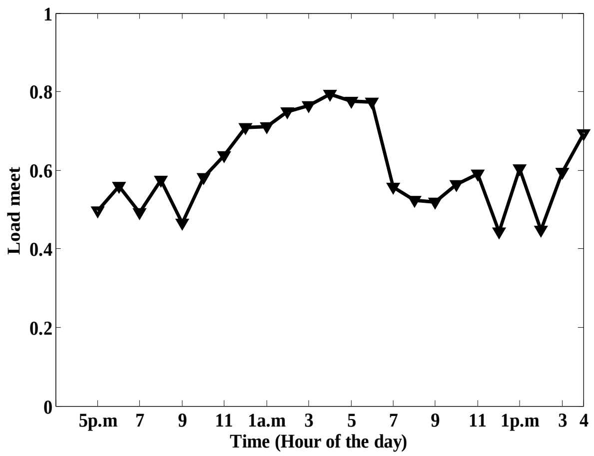


Figure 5: Variation of load meet factor with the period of time in a day.

It is instructive to compare the proposed scheme of offering energy all the time at a reduced level with the existing "on-off" hourly pattern of electricity supply. Figure 6 shows the hourly pattern of existing load shedding for a given day at a given feeder at the Dhanmondi zone for DESCO. The figure shows that except for midnight to early morning load shedding occurs regularly at alternating hours. The average available load from this load shedding approach is also shown as a straight line. The proposed load management scheme offers uninterrupted electricity supply at a reduced level of 1.5 to 2.4 MW. It can be seen that the proposed load management scheme behavior is relatively stable and is close to the average load supply from the existing load shedding technique. This shows that the proposed outage management scheme provides average energy supply to the customers that is similar to that from the present on-off scheme while maintaining continuity of service.

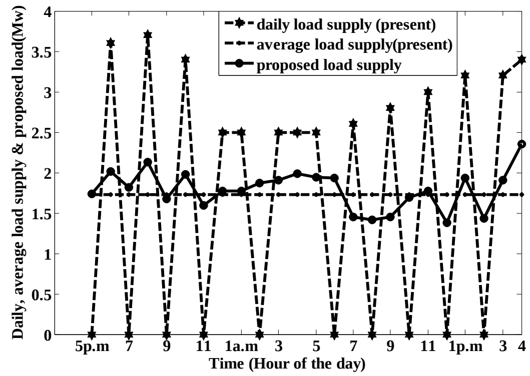


Figure 6: Existing power supply scheme and the proposed outage management scheme.

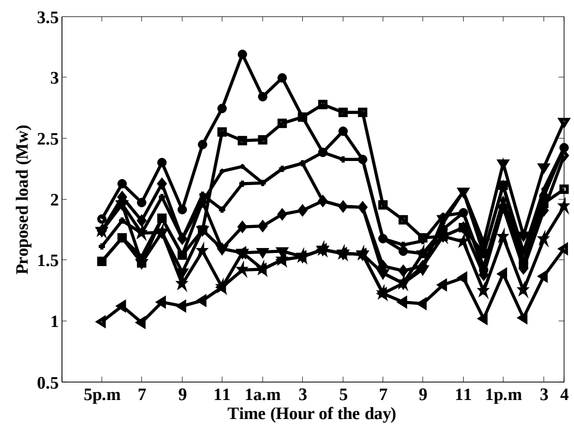


Figure 7: Variation of proposed load across different feeders of the same substation.

The different feeders of the same substation (Dhanmondi zone, DESCO) can also be studied for their allowable load variation throughout the day. The temporal patterns for the allowable load for the individual feeders for the same substation are shown in Figure 7. It can be seen that the variations are correlated depicting common residential customer energy consumption pattern. The variation in peak load supply can be attributed to individual feeder capacity.

Let $p_1(t), p_2(t), \cdots\cdots p_N(t)$ be the supplied load in a substation and $d_1(t), d_2(t), \cdots\cdots d_N(t)$ be the load demand of substation where N is the total number of feeders in that substation. Then total load-meet factor for a given substation can be expressed as

$$LM(t) = \frac{\sum_{n=1}^{N} p_n(t)}{\sum_{n=1}^{N} d_n(t)} \qquad (2)$$

Load-meet factors for different substations (Shyamoli, Dhanmondi and Paribagh) have been computed from data available from DESCO web page. Figure 8 shows the variation of LM(t) for these substations. The plots in Figure 8 reveal that there is a strong correlation of the patterns across the substations. Thus, load distribution at different substations will follow the general pattern from applying the proposed power outage management scheme.

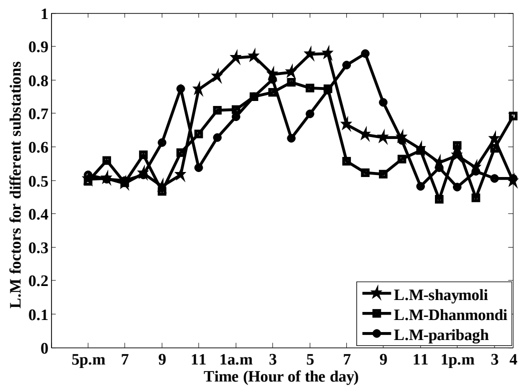


Figure 8: Variation of LM(t) for different substations.

## IV. IMPORTANT IMPLEMENTATION FACTORS

The proposed load management schemes aim at more efficient and economic electricity consumption for customers. Additionally, it offers the distribution companies to provide uninterrupted electricity supply to their customers. One issue may arise and needs to be addressed is that the uninterrupted service occurs at lower load level. The main effects of that are:

1. Individual consumers will need to lower their load level below the sanctioned load. Thus, the consumer needs to plan electricity appliances usage to be within the assigned load level. Thus, for a consumer with 1kW sanctioned load, he/she may be allowed minimum of 450W (45% load meet value in Figure 5) and maximum of 800W (80% load meet level in Figure 5). This can be accommodated by using more efficient electric appliances coupled with smart usage strategy implemented through smart meter.
2. The availability of uninterrupted electricity will lead customers to do away with IPS and battery charging system. The charging of battery during “on” period in the current load shedding scheme can put significant burden on the available supply. Generally batteries designated for use with IPS tend to have shorter charging period by consuming higher current. For example, a 100AH battery at 12 volt can be designed to be completely charged in 3 hours; this implies that with a charging current of 100AH/3H≅33 A,, the IPS system will consume $33\times12 = 396$ WH within the ‘on’ time of 1 hour of the period. This can constitute a significant impact on the customer load and contribute to increase in demand during peak load.
3. For high-rise apartment systems, the supply to lift/elevator and water motor can be left out of the proposed reduction scheme. Since the motors for these heavy electric devices cannot be operated at a reduced supply, the smart meters connected to these devices will be allowed to operate at their rated required capacity. This will reduce the operating expenses of the residents by excluding generators.
4. Hospitals and emergency services can be left out of proposed load reduction scheme. Alternately, they can be guaranteed certain amount of supply throughout the day and difference between this supply and requirement can be compensated by installing generators.
5. Since monitoring of sanctioned load does not take place currently, there is more energy consumption than the allowable limit from the consumer’s side placing an increasing demand on the system. The proposed load management scheme offers monitoring of sanctioned load, and it is expected that this will bring down the demand on the distribution system with more energy-aware consumers.
6. These proposed load management schemes will also drive entrepreneurs to offer green energy solutions at customer premises or at the distribution centers. With additional energy from non-conventional renewable sources, the load management scheme will become more efficient and consumer friendly.

## V. COMMUNICATIONS LINKS FOR THE PROPOSED SCHEMES

The proposed schemes will need a reliable two-way communications link between the smart meter and central substation [9]and between the smart meter and home appliances for automatic control. The communication link to support power outage management can be implemented via wireless or wired infrastructure. For wireless implementations, modems are needed at the smart meters to set up the link, a local concentrator to aggregate the data from multiple smart meters and relays to channelize the data to the central substation. Since the data rate is expected to low to support the scheme, the link can be designed to be small bandwidth systems. The wireless system can also be implemented through a mobile operator where data and control information can be communicated via mobile operator network so that the overall design can be made relatively simple [10]. As an alternative to the wireless systems, wired communication links can be established that will use the existing power distribution lines from the distribution substation to customer premises. This can be implemented using broadband over power lines (BPL) or power line communication (PLC) techniques [11]. Devices that are needed in this case are PLC modems at customer premises, extractor to concentrate the incoming signals, repeaters to keep the signal strength at a satisfactory level and injectors. Except for the cost of these additional devices, the PLC based implementation is expected to be economic since the existing power line network can be used as the communication infrastructure.

As for energy consumption regulation at customer end (schemes A-C), customer response to smart meter alerts and alarms can be either manual or automatic. For scheme A and B, the customer can respond to alerts by planning energy consumption on his own without the need for any smart device. For scheme C, smart switches can be used for heavy load appliances to respond to alarms. In this case, low to moderate data rate links based on Zigbee systems will be sufficient for automatic control of the appliances.

## ACKNOWLEDGMENT

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## VI. CONCLUSIONS

The research presented in this paper focuses on smart meter assisted energy consumption management for consumers and load management for distribution companies. Necessary analysis has been presented to verify the schemes. Analyses reveal that the proposed schemes have the potential to benefit the consumer and also assist distribution companies to provide a better quality of energy supply. The practical operational issues that can result from the proposed load outage reduction scheme have been discussed in details. The existing communications network in Bangladesh is adequate to support the proposed schemes. Thus, the proposed schemes can bring the much needed benefits and quality of electric energy supply and can be implemented through off-the-shelf components using the existing communication infrastructure.

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