# Smart Tariff for Smart Meters In Smart Grid

P.Vijayapriya* Garauv Bapna* Dr.D.P.Kothari*

*School of Electrical Engineering,
Vellore Institute of Technology,
Vellore – 14, India

*Abstract:* **The power grid is aging and congested and faces new challenges and stresses that put at risk its ability to reliably deliver power to an economy that is increasingly dependent on electricity. A growing recognition of the need to modernize the grid to meet tomorrow's challenges has found articulation in the vision of a Smart Grid. The essence of this vision is "a fully-automated power delivery network that can ensure a two-way flow of electricity and information between the power plants and appliances and all points in between". The three key technological components of the Smart Grid are distributed intelligence, broadband communications and automated control systems. It is considered that introduction of "Smart Grid" technology will improve the reliability of power system, quality of supply, efficiency of the power sector apart from being consumer friendly and ultimately reduces line losses. Regardless of how quickly various utilities embrace smart grid concepts, technologies, and systems, they all agree on the inevitability of this massive transformation. Focusing in on the role of Smart Meters, this paper lays out the importance of time shifting the load to off-peak hours to avail the benefit of the proposed smart tariff which aims on cost reduction for consumers for operating during off-peak hours thereby improving the reliability of the whole network.**

*Keywords:*
*smart grid, smart tariff, peak load, off-peak load*

## I. INTRODUCTION

The Smart Grid Technology paves way for increased utilization of green power through Renewable Energy Sources. With the introduction of Smart Grid Technology at Distribution level, the consumer shall have an incentive to switch on their appliances time specific, to have the benefit of choice of low cost power. The existing tariff structure has to be rationalised and 'time of the day' tariffs have to be introduced to provide incentives to consumers.

**Modes of Operation of a Smart Grid**

**Mode 1: Simple Peak load Management**

Every Switch Gear in the power system is remotely controlled by the smart grid system by an RF Signal. The arbitrary devices operated by each consumer are turned off by the system during peak load to stabilize power demand. Certain industries which can run at night and at off-peak loads are switched off to conserve power.

**Mode 2: Tariff Switch over**

A separate tariff with higher costs is set for power consumption during the peak load period. The schedules of peak and off-peak loads in a day are analyzed through statistical reports. The period of peak load is communicated to the consumer (E.g. peak load Mon toFri 1 p.m. to 3 p.m.). An energy meter with a real time clock module at the consumer ends counts units separately for power consumed during peak and off-peak loads. During billing, Power consumed during peak loads are charged higher, while normal tariff is followed for off-peak loads. The periods of peak load can be altered and communicated to the Energy meter which is equipped with an RF Receiver to receive the data.

**Mode 3: Consumer Priority**

Each consumer is given a priority based on their application and need.

For LOW priority consumers, power is cut off during peak load and during the off-peak load power is supplied at normal tariff. For MEDIUM priority consumers, power to arbitrary devices are turned off during peak load and power is supplied at higher price but during off – peak time, power is supplied at normal tariff. For HIGH priority consumers power is available during peak time and off-peak time at higher price without interruption.

**Mode 4: Automatic Mode**

Load on the Grid is monitored continuously and arbitrary devices are turned off automatically during peak loads. Irrespective of consumers and their priorities the arbitrary devices alone are turned off by the system.

So in this paper a hardware setup is developed to intimate the customer to switch off the load during peak time and there by avail the benefit of cost reduction under the new tariff scheme developed for using energy in the off-peak time.

## II. NEED FOR A SMART TARIFF STRUCTURE and SMART METERS

As electricity markets are liberalized, consumers become exposed to higher electricity prices and may decide to modify their demand to reduce their electricity costs. In comparison to the French market, where a range of prices are available to the consumer during different times of the year, there is only one price scheme used for the entire year in India. Residential consumers are charged a fixed price for the installed capacity. An increase in the price of electricity consumed with the rise in consumption encourages users to save energy. An increase in the price of reactive power can be implemented during peak summer months to discourage the excessive use of high inductive load

*Thomas M. Chen* [3] says, the smart grid will depend on a two-way digital communication networks between power utilities and smart meters installed at house. In the reverse direction, smart meter provides dynamic time-of-use (TOU) pricing information to the consumers. According to *Saba Kauser* [8], electricity markets are liberalized and consumers are exposed to higher electricity prices and may decide to modify their demand to reduce their electricity cost. TOU will be very useful tool to achieve it. *Geoffrey Rothwell* [9] says buying and selling electricity involves at least three productive activities: generation, transmission, and distribution. These activities can be bundled in a single market in which producers generate, transmit, and distribute electricity to consumers and vice versa. *Giuseppe Mauri* and *Diana Moneta* [14] say, Operation of future power systems will be shared between central and distributed generators. Control of distributed generators will need to be aggregated to form micro grids or 'virtual' power plants to facilitate their integration both in the physical system and in the market. In such a scenario, smart metering will have to accomplish the important role of providing prosumers (producers & consumers) not only with appropriate reading of relevant fiscal parameters, but also with the possibility to send market and network signals to prosumers.

## III. SMART METERS

The smart grid will depend on a two-way digital communication network between the power utility and smart meters installed at houses- a system generally referred as an advanced metering infrastructure (AMI). A smart meter continuously monitors the electricity usage at home for the utility company. In the reverse direction the smart meter provides dynamic time-of-use pricing information to the consumers (e.g. higher tariffs during peak demand). The feedback information might also include instant reward incentives (e.g. to shut down appliances during peak demand), detailed data about the consumers energy consumption, or information about the consumer's contribution to the overall system savings and carbon emissions.

The bidirectional exchange of information will change the traditional relationship between energy suppliers and consumers into a more cooperative one for mutual benefit. Given more information about the system, consumers are expected to benefit by making more intelligent decisions about their energy usages and expenses. At the same time, energy suppliers can manage demand and supply more effectively. Peak demand can be handled better by giving incentives to consumers to turn off high voltage appliances If electric vehicle become common, the smart grid will be able to sense and accept consumer-generated energy (e.g., from solar panels and electric vehicles) to further reduce the need for "in order to be ready to meet sudden demand spikes. The assumptions and requirements for smart critical infrastructures are very different, implying that the networks for smart cities should be engineered quite differently.

In the migration towards ICT-enabled power systems, smart metering [7] plays a crucial role. Smart metering allows energy efficiency to be attained via price stimuli in different tariff schemes. Smart metering has excellent control abilities. For instance, it allows to shut down several customers simultaneously on short notice –in order to balance the grid in case of an incident– or for demand response –for usage flattening or load shifting–or for integration in home automation systems –for automatic response to varying electricity prices–etc. As such, smart meters are an indispensable enabler in a context of smart grids which deploy advanced information and communication technology to control the electrical grid. Via the tariff schemes, smart meters can play an important role in changing the consumption pattern of residential users.

## IV. EXISTING TARIFF

In India there are basically two main types of tariff's viz. LT tariff and HT tariff. The LT tariff mainly considers energy consumption whereas in HT tariff apart from energy consumption there are other components such as maximum demand charges spinning reserve", the expensive practice of keeping turbines spinning, power factor charges; KVA demands charges and TOU charges.

Power transmission in India was divided into five Regional grids in the 1960s. Each Region comprised several State Electricity Boards (SEBs) and thermal, nuclear & hydro generating companies responsible to the Central Government. The SEBs frequently draws power much in excess of their entitlements from the Central generators, particularly during peak hours. During off peak hours, the SEBs tends to operate their own generators and draw less than their commitments from the Central plants.

Poor investment in reactive compensation causes the SEBs to also draw reactive power from the EHV grid. This results in severe voltage drops with some 400 kV sub-stations frequently operating at voltages as low as 300kV. The already serious situation is further deteriorating year by year due to inadequate generating capacity, poor availability of existing generating capacity, lack of spinning reserve during peak hours, inadequate VAR compensation and lack of vital load dispatch and communication facilities for operations. To tackle the various problems listed above, as also to provide a viable commercial and operational mechanism for integration of captive generation with regional grids, government of India implemented Availability Based Tariff (ABT) structure for EB's.

Power from Central Government-owned generating stations was being supplied to the State Government-owned vertically integrated utilities as per simplistic, single-part, constant (Rupees/kWh) tariffs. Although each state had a specified share in the above referred Central Government-owned generating stations (which supply about 30% of the total power), the payments by the state to Central generating companies were based on net energy drawn in a month, disregarding the state's shares and any upward or downward deviation from schedules. It was in the above backdrop that Indian engineers developed and introduced a new and unconventional concept- tariff linked to frequency.

To encourage their consumers to modify their demand pattern in a beneficial way, utilities have adopted variety of DSM (Demand Supply Management) measures such as two-part tariff and interruptible load contracts. While these special tariffs are mutually beneficial, it is not always clear that the benefit for the consumer is proportional to the utility. These adjustments to be done on the load side are termed as demand elasticity and the tariff's to be used for achieving the same are known as TOU (Time of Use) tariff. In terms of the concept of elasticity this means that there is present not only self-elasticity, where demand rises and falls inversely as the prevailing price, but there also exists a cross-time elasticity, whereby demand at one time may well depend on the prices prevailing at other times.

## V. PRINCIPLE OF SMART TARIFF

As electricity markets are liberalized, consumers become exposed to higher electricity prices and may decide to modify their demand to reduce their electricity cost. Real Time Pricing (RTP) and Time of Use pricing (TOU) function as load management tools. The magnitude of variation of price (for e.g. weekly or seasonal) would require setting up a model to consumer behavior. The model relies on the concept of demand elasticity across time, degree of consumer economic rationality and on the supply side, on the price formulation model.

Under this tariff structure, two components are considered:

1. Base rate based on Cost of Service (COS).
2. Time-of-use charges based on Cost of Unserved Energy (CUE).

The price will be the actual marginal cost of production, appropriate corrected for transmission and distribution losses. When the production cost is high and less efficient plan has to be run, the selling price will be high. At times of low load, when high efficiency base load generators carry the bulk of load, the selling price will be low. Sufficient price incentives will be given to move away load from high load to less expensive low-load period. Investments in installed capacity will be curtailed. The average fuel cost will be reduced. Both these savings will be reflected in a further reduction in consumer electricity bills.

The major part of the tariff for the station's output is based on the **station's availability**, rather than on aximum capacity (MW / MVA) or demand as in a conventional two-part tariff.

Payments under the **Smart Tariff** will basically comprise three parts –

1) Clock charge

2) Energy charge

3) Deviation from normal frequency (confidence interval charge)

1. The Clock charge for a time block (which may be one hour or one day) is paid at specified Rupees per MW per day, basis for the declared MW output capability of the station for that particular time block.
2. Clock charge payment would be made as per the specified Rupees per *MW per day*. *Rates* will be applied on the declared plant output capability for the day, irrespective of the actual capability and actual generation.
3. The Clock charge is meant to cover the total fixed cost of the generating station, e.g. interest, depreciation, fixed operations &maintenance (O&M) cost, insurance, return on investment.
4. Depending on the declared availability (which is given by the station on a day ahead basis), the purchaser(s) would specify the generation schedule for the day, before the day starts. The ENERGY CHARGE would be paid for the energy supplied as per this generation schedule.
5. The energy charge is meant to cover the variable cost of the station that **is the cost component which changes** with the amount of energy generated.
6. Confidence interval charge is meant for the frequency deviation charges. The operators will be charged for the deviation from normal frequency i.e. 50 Hz in terms of frequency cost.

## VI. FORMULATION OF SMART TARIFF FOR UTILITIES

Following are some equations [9] used for estimation as well as comparison for smart tariff with the existing tariff structures:

$$\mathbf{P = a - b^*Q_d} \qquad (1)$$

Where, a & b are the parameters which depends on the varying quantity.

P is the price in Rs. /unit

Qd is the demand in MW.

Alternatively, it can be expressed as

$$\mathbf{\ln P = c - d^*\ln Q_d} \qquad (2)$$

Now let us consider a general case.

A linear demand function is represented as

$$Q_d = a\text{-}b^*P$$

And linear supply as

$$Q_s = -c + d^*P$$

At equilibrium, $Q_d$=$Q_s$

Practically, there can be a lag in supply because a firm cannot respond immediately to changes in demand. Assume there is a demand shift and supply responds to last period's price (which can be an hour, day, week, month, and year). Therefore a new demand and supply can be represented as

$$Q_d\,(t) = a' - b'^*P\,(t)$$

And supply is represented as a function of lagged price P (t-1)

$$Q_s (t) = -c + d*P (t-1)$$

At equilibrium $Q_d$ (t) =$Q_s$ (t)

Therefore, [a’-b’*P (t)] = [-c + d*P (t-1)]

Now shifting ahead one period and rearranging terms

$$P(t+1) + (d/b)*P(t) = (a’+c)/b$$

This is a first order differential equation which can be solved to yield the following time path for price.

**P (t) = (Po – P*)*(-d/b) ^t + P*** (3)

Where, P* = (a’+c)/ (a’+c)

Where P* is a long run equilibrium price

Equation (3) could be used to calculate the long run equilibrium price.

In order to examine the importance of the proposed scheme, a case study is done on public water works. It is a major load and of constant nature. After getting the actual slots of its operation, we have tried to develop a new load profile wherein the water pumping load is shifted from peak to off-peak hours. Data obtained:

TABLE 1: TIME SHIFTING OF LOADS

| NO. OF HOURS | IDEAL DEMAND ( MW) | ACTUAL DEMAND (MW) |
|---|---|---|
| 0-9 | 100 | 120 |
| 9-12 | 100 | 60 |
| 12-18 | 100 | 120 |
| 18-22 | 100 | 60 |
| 22-24 | 100 | 120 |

As per the existing tariff, the 100 MW demand is assumed ideal and are charged according to that, but if the actual load is analyzed is different

As per the linear demand function, from equation (1)

**P = a – b*Qd**

Where, P = price

a = constant depending on off – peak demand.

b = constant depending on peak period and is generally calculated as percentage of rate of interest.

For given Load pattern, comparison is done between existing tariff and proposed one.

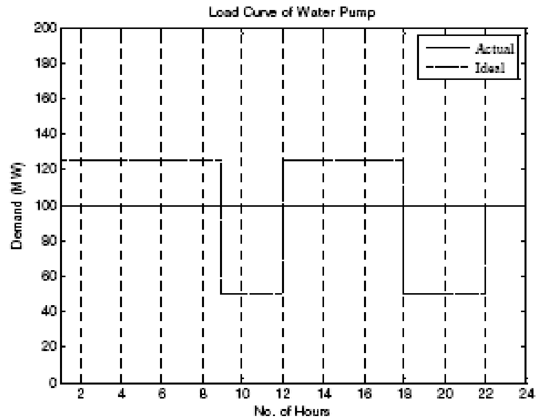


Figure 1. Load curve of water pump

EXISTING TARIFF

Let the rate of interest, r is 10 %

a = on – peak time = 24, since demand is assumed constant.

Qd = 100 MW

b = 0

Therefore, P = 24-0= **24 Rs/unit**

PROPOSED TARIFF

a= 17 (on peak) b = 7 (off peak)

Therefore,

On – peak cost P = 17 – 0.07(120) = 8.6 Rs/unit

Off-peak cost P = 17 - 0.17(120) =6.8 Rs/unit

Total cost = 8.6 + 6.8 = **15.4 Rs/ unit**

## VII. HARDWARE IMPLEMENTATION

Power Station is modeled as shown in the figure. The Micro controller used in the project is 89S52. It has 8k bytes of on chip programming ROM. It has 256 bytes of RAM. It has 3 Timers. There are 4 ports each consisting of 8 pins thus totaling to 32 input pins. There is one serial port and there are 8 interrupt sources. The IR sensors are connected to port 1 of the micro controller. The MAX232 (serial port IC) is connected to port 3 of the micro controller. The on-chip Downloadable Flash allows the program memory to be reprogrammed in-system through an SPI serial interface or by a conventional non-volatile memory programmer. By combining a versatile 8-bit CPU with down loadable Flash on a monolithic chip, the Atmel AT89S52 is a powerful microcomputer which provides a highly flexible and cost effective solution to many embedded control applications.

For programming the Microcontroller, KEIL C programming is used. The Microcontroller is programmed for serial communication by enabling Timer 1 and also the coding is written so as to collect the digital data from the Analog to digital convertor. A Keil cross compiler is software, which compiles a source code of one environment as an object file to be executed in different environment. It is broadly classified into development and simulation. The simulation is handled by D Scope

POWER STATION

Instead of wireless communication, wired communication is used for demonstration purpose. The power consumed by the substations is given to the microcontroller and is displayed in LCD display. If the power drawn by the substation is above the capacity of the power generation of the power plant safety level, the power plant controller gives a signal that it is running in peak load and requests the substation and distribution station to shut down the unwanted load to avoid the peak load. The relay units is used to cut the supply to its substations when the demand is more for the power.

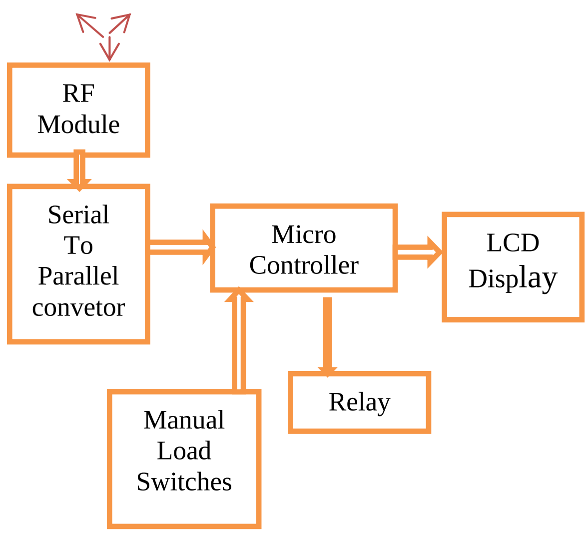


Figure 2 : Block Diagram of Power Station

DISTRIBUTION STATION

The LCD in the distribution station displays the power in the distribution station and the substation. If the substation receives the signal that the power station is running in the peak load, the substation switch off the unwanted load using the relay units. The relay units are switch off when the microcontroller receives the command from the power and substation and according the relay is switched on and off .

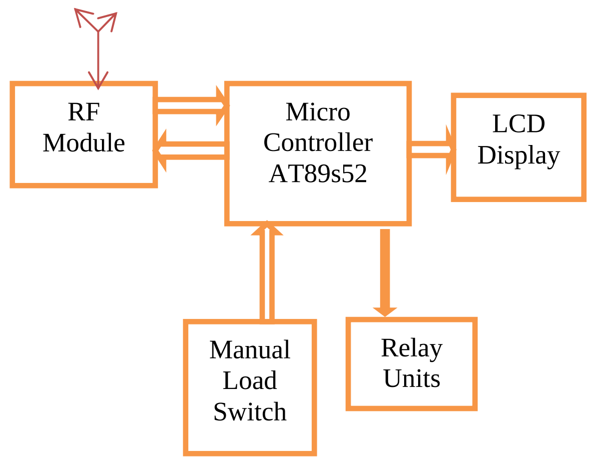


Figure 3 : Block Diagram of Distribution Substation

## CONCLUSION

The smart meter demonstrated in this project could help consumers as well as utilities for proper communication and making both of them aware that how much power is actually needed and how much money could be saved. It will encourage the plant operators to maintain the highest possible station availability, and will have a great significance in power shortage situation. This will discourage generating stations from over-generating during off peak (power surplus) hours, while encouraging them to maximize their generation during peak load (power deficit) hours. This would reduce frequency deviations on the grid. The tariff for utilities based on ABT will be very useful for designing further tariff structures based on frequency and thereby guiding the utilities to drive the generation towards cost economic model. For hydro-electric plants whose actual variable cost is zero, if the above criteria are strictly applied, their tariff would comprise of only the CLOCK CHARGE. The above thesis will provide a strong platform for the future research on smart grid and thereby help the current system to move in better direction.

## REFERENCES


[1] The National Energy Technology Laboratory, U.S. Department of Energy.

[2] Muhammad Ali Mazidi , Janice Gillispie Mazidi Rolin D. McKinlay,: "*The 8051 microcontroller and embedded system*", 2nd edition, Pearson/Prentice Hall, 2006.

[3] Thomas M. Chen : "*Smart Grids, Smart Cities Need Better Networks*", IEEE Network, vol. 24, no. 2, March 2010

[4] Steven E. Collier : "*Ten Steps to Smarter Grid*", Rural Electric Power Conference, IEEE 2009

[5] Bob Saint : "*Rural Distribution System Planning Using Smart Grid Technologies*", IEEE Rural Electric Power Conference, Ft. Collins, 2009

[6] G. Deconinck, B. Decroix : "*Smart Metering Tariff Schemes* combined with distributed energy resources", ESAT/ELECTA, Critical Infrastructures, CRIS 2009

[7] Bhushan, B.; Patnaik, S.; Jhanji, S.: "*Innovative Tariff And Metering For Indian Grids*", Eighth International Conference on Metering and Tariffs for Energy Supply, 1996

[8] Mrs. Saba Kauser M.Shaikh, Anjali A. Dharme : "*Time of use Pricing – India, A case study*" Third International Conference on Powersystems, Kharagpur, INDIA.

[9] Geoffrey Rothwell, Tomas Gomez, Martin Schetzen : "*Electricity Economics: Regulation and Deregulation*", John Wiley & Sons.

[10] "*Grid 2030 - A National Vision For Electricity's Second 100 Years*", United States Department of Energy Office of Electric Transmission and Distribution.

[11] Smart Grids, Electrical India, by Dr. Vithal N Kamat

[12] F. Wallin, IEEE member, C. Bartusch; E. Thorin; T. Bdckstrom; E. Dahlquist : "*The Use of Automatic Meter Readings for a Demand-Based Tariff*", Transmission and Distribution Conference and Exhibition: Asia and Pacific IEEE/PES, 2005 .

[13] Deshmukh, S.R.; Doke, D.J.; Nerkar, Y.P.: "*Optimal Generation Scheduling under ABT using Forecasted Load and Frequency",* Joint International Conference on Power System Technology and IEEE Power India Conference, POWERCON 2008.

[14] Giuseppe Mauri, Diana Moneta, Carlo Bettoni, Giovanni Colombo: "*Smart Multimetering and Dual Fuel Tariffs for Integrating Active Customers in Smart grid*', CIRED 20th International conference on Electricity Distribution, 2009


Mrs. P. Vijayapriya was born in Vellore, India. She received her Bachelor's Degree from Vellore Engineering College, Vellore, India in 1998 and Masters degree from Vellore Institute of Technology, Vellore, India in 2006 and doing her doctoral degree in Vellore Institute of Technology.

Since 2000 she is working in School of Electrical Engineering, Vellore Institute of Technology, Vellore and her area of Research interest in Ph.D is Smart Grid. She is associate member of Institution of Engineers and System society of India

**Prof. Dr. D.P. Kothari**, obtained his B.E [Electrical], M.E. [Power Systems] and Doctoral Degree in Electrical Engineering from the Birla Institute of Technology & Science, Pilani. His fields of specialization are Optimal Hydro-thermal Scheduling, Unit Commitment, Maintenance Scheduling, Energy Conservation (loss minimization and voltage control), and Power Quality and Energy Systems Planning and Modelling.

**Prof. Kothari** is the recipient of National Khosla Lifetime achievement Award [2005] from Indian Institute of Technology, Roorkee, National Award for Science and Technology [2001] from the UP Government at the annual convention of ISTE, Bhubaneswar, Eminent Engineering Personality from the Institution of Engineers [2001].

Prior to his assuming charge as Vice Chancellor of VIT University, he was the Professor of Centre for Energy Studies, Indian Institute of Technology, New Delhi. He also served as Director i/c, IIT, Delhi [2005], Deputy Director [Administration], IIT, Delhi [2003-06], Principal, Visvesvaryaya Regional Engineering College, Nagpur [1997-98], Head, Centre for Energy Studies, IIT, Delhi [1995-97]. Published 625 research papers in various national and international journals and conferences, guided 27 PhDs, 55 M.Techs', authored 20 books in Power Systems and other allied areas.

**Prof. Kothari** is a Fellow of the Indian National Academy of Engineering [FNAE], Indian National Academy of Sciences [FNASc], Institution of Engineers [FIE] and senior member, IEEE.

Gaurav Bapna did his B. Tech in Electrical and Electronics engineering from VIT and presently he is working as a Graduate Engineer Trainee in Jindal Steel and Power Ltd.,Raigarh.