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Dynamic Pricing for Residential Consumers in Electrical Distribution System

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Abstract

The fundamental challenge in the operation of the electrical network is to execute a real supply and demand system that will be completely reliable. Genetic Algorithm (GA) and Ant Lion Optimization (ALO) are applied for the placement and sizing of DG. The significant purpose of GA, and ALO is to curtail the primary distribution energy losses as well as voltage deviation. Allocation of DG at the proper location with the appropriate size in the distribution system gives techno-economic benefits. The simulation results of the GA optimization method revealed a significant reduction in power loss up to 91.76% and by ALO the loss reduction is 91.28%. Also, it is observed that an exceptional improvement of up to 11.90% by GA and 11.75% by ALO in tail-end node voltage, which is a real problem for rural distribution systems and critical from the customer's point of operation. To reduce losses in secondary distribution, the reduction in utilization of energy is necessary without disturbing the priorities of supply. Hence load shedding is one of the options that is presently done. But if one of the consumer categories (residential) has offered a dynamic tariff, the consumption to this category will be reduced, giving benefits in terms of total bill charges. However, the utility can divert this saved energy to high-cost consumers (industry), will get more revenue with same energy input.
Keywords: Distributed Generation (D.G), Global System for Mobile communication (GSM), Smart meter, tariff, Genetic Algorithm (GA) and Ant Lion Optimization (ALO)

1. INTRODUCTION

In the present scenario, electrical energy from conventional generating centers with the help of high voltage transmission lines is delivered to the distribution networks and then transferred to consumer centers. One of the fundamental challenges in the operation of the electrical network is to execute a real supply and demand system that will be completely reliable. Genetic Algorithm (GA) and Ant Lion Optimization (ALO) are applied for placement and sizing of DG. The significant purpose of performance analysis of the Genetic Algorithm (GA) and Ant Lion Optimization (ALO) is to curtail the primary distribution energy losses as well as voltage deviation. Allocation of DG at proper location with appropriate size in the distribution system gives many techno-economic benefits. The simulation results of the GA optimization method show that there is a significant reduction in power loss up to 91.76% and by ALO the loss reduction is 91.28%. Also, it is observed that an exceptional improvement of up to 11.90% by GA and 11.75% by ALO in tail-end node voltage, which is a practical problem for most rural distribution systems and also critical from the customer's point of operation. Electric power companies are usually monopoly utilities, hence regulatory agencies approve consumers' electricity tariffs. Electricity consumption rates are fixed according to different consumer categories. These electricity rates are not based on time, season, or time of day usage for any customer except industrial customers. Domestic consumers use a large number of modern electrical appliances due to their modern lifestyle, which results in high electricity bills, the extent to which some of the consumers steal electricity or do not pay electricity bills. As a result, losses in the distribution system increase and the revenue generated decreases. In this paper, for household consumers, smart energy measuring devices and electricity rates depending on the time of day are being proposed. In which different types of electricity rates like rates up to certain stages, rates according to the time-of-day use, etc., will be available in meters. Customers will be able to choose these rates according to their convenience of use and this meter will generate an energy bill according to the selected electricity rate and send the text message of the bill on the customer's and utility official's mobile. Also in this meter, facilities have been provided like theft detection, tampering in the meter, bypassing of meter, using more than the approved electrical load, and if any of these are found, will immediately send a message to the customer and distribution company official about misuse.

In the last few decades, developing countries are putting more and more stress on the up-gradation of the electricity supply and infrastructure. On another side due to the modernization of living and development in all sectors, the use of electricity increases and becomes very fluctuating. Fluctuations in demand have another effect of the decrease in generation efficiency. The present centralized energy system based on a reduced number of large power plants produces electrical energy utilizing fossil fuels. In view of low line loss, the electricity is transmitted at high voltage for long-distance and distributed through low voltage lines to consumers. The actual utilization of electricity has to pass through certain phases initially generation, increase or decrease in voltage level for that passing through switchyard for transmission through power and distribution lines and then distributed to the consumers. The system is generally divided into a number of subsystems: generation, transmission, and distribution. The power stations included a generation subsystem, that needs to draw energy from a primary or natural source to produce electricity. The transmission subsystem transmits the power at a high voltage level and makes it available to the distribution subsystem at a medium voltage level for further low voltage distribution of energy. In such a structure, the energy flows from the generation to the user are unidirectional, in this case, the consumer is only a passive role as a simple energy consumer. However, in recent years, "distributed generation", due to strong incentives, has considerably developed over the conventional centralized production, to meet the peak demand, this enables the consumer to active role in the power structure [1][2]. This generated energy is synchronized by a means grid on a single bus bar for utilization. Energy efficiency is one of the important issues which need urgent attention, as energy is strained to the extreme now a day. In this process whatever expenses occur has to be recovered by costing this utilized energy by consumers. Hence it is necessary for the actual utilization of energy by the consumer to be measured. Nowadays digital devices are preferred instead of analog measuring instruments as digital energy meters give better security and control over analog electromechanical meters. The main reason for the replacement of electromechanical energy meters is the losses. Losses can be divided in, Technical and Non-Technical/Commercial losses. Technical losses are the actual energy loss occurring while power is transmitted for the distribution of energy. In developing countries like India, especially in remote areas, electricity theft is a common practice, also a tendency to nonpayment of energy bills can be referred to as non-technical or commercial losses [3].

In developing countries with high populations, the use of electricity is an essential part of life. Consumers particularly residential are using maximum electrical energy appliances causing high energy charges. Hence the tendency to pay a small amount leads to power theft is one of the most prevalent issues which cause economic loss as well as irregular supply of electricity. This gives barriers to modification of infrastructure, generation, and renovation of equipment. It is also observed most of the consumers use the appliances during peak hours in which the voltage may collapse due to increased demand, compensation for this voltage collapse during peak hours may be load shedding but this is not a long-term solution. Also, this solution, in the digital world may raise problems. Electricity theft incorporates tampering with meters, bypassing a meter that shows a low meter reading, billing irregularities, and unpaid bills. Billing irregularities consist of inaccurate meter observation and intentional managing of the bill by the consumer in exchange for illegal payments by bribing servicemen [4].

The tariff decided by the utility may not satisfy consumers' participation in conservation programs. In demand-side management, it is necessary to value the consumer which can save energy during peak periods. In view of this, there must be some option in terms of reduction in energy charges, then it will be possible for the maximum number of consumers will change their energy utilization period which will help to grid for the reduction in burden. Electrical energy is employed to make every system more comfortable and adequate, tends to increase in demand for electrical energy day by day. The power utilities are finding additional energy sources to the conventional ones, due to the progressive decline of fossil fuels and increased attention towards the environmental aspects. As an outcome, the distributed generation is to a greater extent broadly spreading. In this new dimension era known as the "smart grid", to achieve and maintain high efficiency and requirements, it is necessary to change its operating management of energy distribution. With the help of the proper location of distributed generation transmission losses can be kept within the limit, but nowadays on the distribution side not only transmission and distribution loss but a large amount of commercial loss is also observed. This paper presents in section-II related work. In section III, problem formulation with technical and non-technical losses and tariff issues are discussed. Section IV describes the proposed system. The result and discussion are presented in section V. The paper is concluded in section VI.

2. Related Work (Literature Review)

The author has proposed a GSM network prepaid energy meter that has virtual access to every household across different countries. Using this smart energy meter prepaid consumption of electricity is implemented with the facility of controlling energy theft through GSM communication. The electricity theft information is communicated to the central utility authority and therefore actions can be taken for reducing electricity stealing and ensuring revenue collection [4]. The author presents an approach for theft identification, location, and determining magnitude by using Power line communication and advanced metering infrastructure for the distribution system. More accountability in the system, accurate information on location, and degree of electricity theft is important. The financial status and power quality can be improved by the correct estimation of power theft in real-time [5]. For calculating technical loss, the predictive model for a branch by incorporating the temperature dependency resistances in a distribution network to overcome the disadvantage of constant resistance. The theft has been detected by using the data from the energy meter and data from the distribution transformer [6]. The prepaid energy meter is proposed with the advantage of the GSM network connected to every household. The GSM communication implements prepaid charges for electricity consumption as well as a facility for controlling theft. The information about electricity theft is directly reported to the central utility authority and legal action against the accused consumer can be taken immediately to control theft to a great extent [7]. The development of various electronic meters is a continuous process; the use of GSM provides a number of advantages over others that have been previously used. The power consumption recording can be transmitted more frequently to a remote station. This enables to generate timely bills for consumer, also it helps to understand energy demand patterns, manage meter failures more efficiently by the utility. The system has much less risk since human interaction has been minimized [8]. An intelligent energy meter is beneficial for both energy providers and consumers and easy to install. Manual efforts with this meter can be reduced which is cost-effective and users will be aware of their energy consumption. The proposed system avoids electricity theft, makes the energy meter tamper-proof and increases revenue. It can be expanded for automatic power cutting if the bill is not paid [9]. The author proposes an energy consumption calculation-based number of pulses and implemented using Microcontroller in an embedded system domain with continuous monitoring of consumption. Disconnection of power supply without human involvement for nonpayment of energy charges is possible. The main advantages of the system are easy for consumers asses information, theft detection, disconnection of supply [10]. Through remote monitoring and SMS informing, with abnormal readings in the customer electricity meter, the system may be able to help the utility to the reduction in the incidences of electricity theft. Billing system mechanization has been achieved for the customer as the meter monitors the load on a timely basis by removing the error in manual reading, bill manipulation, and its attached consequences of time. The presented work was also carried out for automatic disconnection and connection for no balance or recharge by prepaid amount respectively. Further detection of physical activities for other illegal acts around the meter in each household is monitored by cameras on the customer meter [11]. Electricity stealing prevention becomes a big problem for the electricity utility. In the present system, power theft is determined based difference between the total power consumption, received the delivered power data with the number of users. There is no specific way to find out the power theft. The idea of detection of power theft is proposed by using two current sensing parts one is the Hall sensor and the energy meter current measure the current transducer. The hall sensor is installed at the service receiving point. By comparing the two inputs, for the difference if any present between the two values the message to the concerned authority is sent with the help of the GSM system [12].

3. Problem Formulation

a. Transmission and Distribution Losses (T&D Losses)

The process of supplying electricity to consumers consists of energy loss due to technical and commercial reasons. The technical loss comprises energy loss in the conductors, transformers, and other equipment used for transmission. Technical losses can be reduced to a certain level as these are inherent in a system. The main sources of the commercial losses are pilferage bypassing meters, hooking, defective meters, errors in meter reading, and a non-estimated un-metered supply of energy. Transmission & Distribution (T&D) loss includes commercial and technical losses. Non-recovery of the billed amount is another component of commercial losses, which is reflected in revenue collection efficiency. T&D losses added with loss in the collection give us aggregate technical & commercial (AT&C) losses. Transmission & Distribution losses (T&D losses) can be determined as shown in eq (1)

$$\%Loss_{T\&D} = \frac{E_i - E_b}{E_i} \times 100 \qquad (1)$$

where E_i is total energy input in the system, E_b is total energy billed

Aggregate technical and commercial losses (AT&C losses) is as shown in (2)

$$\%Loss_{AT\&C} = \frac{\eta_c - \eta_b}{\eta_c} \times 100 \qquad (2)$$

where, η_c is collection efficiency, η_b is billing efficiency determined as shown in eq (3) and (4)

$$\eta_c = \frac{KWh_b}{KWh_i} \times 100 \qquad (3)$$

$$\eta_b = \frac{B_c}{B_b} \times 100 \qquad (4)$$

where KWh_b is total number of units billed, KWh_i is total number of units input, B_c is total billed amount collected, B_b is total amount billed/ generated [13].

b. Tariff for Residential consumers

Electric power companies are generally a monopoly utility, so consumers' electricity prices are approved by regulatory agencies. These prices are considered electricity tariffs or tariffs. These tariffs are defined per category of different consumers. Such electricity tariffs do not show periodic (e.g., hourly, day-to-day, season-to-season) costs of electricity except for industrial category consumers. One of the demand side management techniques is dynamic pricing, which can reduce the burden in peak hours by offering electricity rates at different time periods of the day.

To meet peak load utility has to add some generating units, these generating units are idle during off-peak demand. This may result in an increase in loss and decrease inefficiency. To transfer some peak load to off-peak load dynamic pricing will be a solution, also reduces capital investments. Retail prices offered by the utility are generally blocked rate tariffs, in which the number of slabs is provided with a different rate per unit. As the consumption increases, the slab will increase, and hence the rate of electricity increases. However dynamic price offers an opportunity for saving in electricity charges while shifting some of the load from peak period to off-peak period. Dynamic pricing is an effective tool for revenue management that has results from various fields such as travel, telecommunication, online retail, etc. Existing state utility offering following tariff approved by state regularity authority are shown in table 1.

Table 1 Existing tariff structure for residential consumer

Sr. No.	Slab	Energy rate/unit	Wheeling Charges	Fixed Charges	Energy Price
1	Up to 100 units	Rs. 3.46	Rs. 1.45 per unit	Rs. 100 per connection	16 % on energy amount
2	101 to 300	Rs. 7.43			
3	301 to 500	Rs. 10.32			
4	More than 500	Rs. 11.71			

Fuel adjustment charges are applied according to the fuel cost in that particular month.

c. Problem Statement

The consumers utilize electrical energy for their easy lifestyle due to which the energy charges increased causing the mindset of some consumers to do theft with the help of interference in digital energy meter. This increases unbilled energy use, treated as a loss by the utility which is increasing day by day. For reducing the gap between revenue to be collected and actually received the power industries rises the energy charges after reviewing the energy supplied and returns claimed at every financial year. In other words, the consumers paying regularly will suffer owing to high charges. Residential consumers are having fixed tariffs given by utility and no options are provided for a choice of the tariff as per the use of energy in a day, in the present scenario.

4. Proposed System

To enable the residential consumer to shift their load from peak period to other than peak period the Time of Day (ToD) tariff for the residential consumer is proposed. According to the daily load curve shown in fig 1 of residential consumer, three spans of a peak, flat, and valley for day and night time separately are prepared, hence total time period of a day is divided into six spans as shown in table 2. the Time of Day (ToD) tariff for the residential consumer by determining the base rate for present electricity tariff approved by the regulatory authority and keeping it constant is proposed in this paper.

The result shows saving in consumer energy prices and saved units in peak periods can be utilized by the utility to the consumers with higher tariff rates, hence both consumer and utility will be benefited.

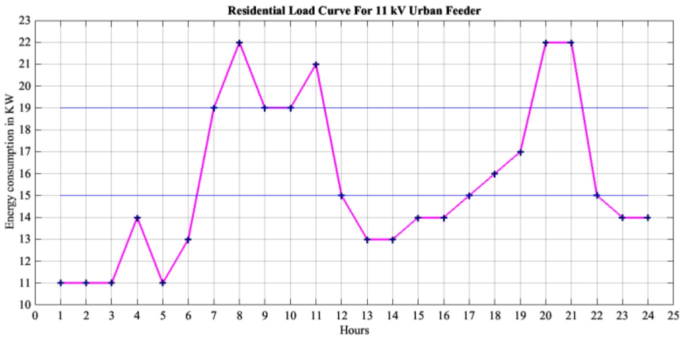

Fig 1: Typical residential daily load curve for urban feeder.

To find the rates of energy of different time periods of the day initially the time slot is divided into three categories as peak, flat, and valley period for day and night period separately.

Table 2 Time slots for proposed residential ToD tariff

Sr. No.	Slot	Day time	Night Time
1	Peak	07 to 11 hrs.	19 to 22 hrs.
2	Flat	11 to 12 hrs.	17 to 19 hrs.
3	Valley	12 to 17 hrs.	22 to 07 hrs.

Considering the present approved rate of energy by regularity authority new rates for dynamic pricing is calculated as follows, Basic rate per unit for new slab= (summation of energy rate per unit of the current slab covered in new slab + fixed charge per unit + wheeling charges per unit) / number of current slabs covered

$$R_b = \frac{\left(\sum_{i=1}^{n} a_i\right) + R_c + R_w}{n} \qquad (5)$$

where R_b is basic rate for new slab, a_i is the rate of energy per unit of the ith slab, R_c is the fixed rate per unit, R_w is the wheeling charges per unit, n is the total number of current slabs covered in the new slab. As the advantage of dynamic pricing is more for utility in terms of saving in capital cost, saved energy units can be sold at a higher rate to other category consumers, reduced loss on residential feeder due reduction of load. Hence for getting some advantage keeping revenue collection level as it was to consumer the consumption slab is slightly changed compared to the approved slab by regularity authority.

Table 3 Basic rate for proposed dynamic price

Sr. No.	Consumption Slab	Per unit charge of slab covered in this slab in Rs.	Fixed charge per unit	Wheeling Charge per unit	Number of existing slabs covered	Basic rate per unit in Rs. R_b
1	Less than 150 units	3.46	0.66	1.45	1	5.57
2	151 to 350	3.46+7.43	0.33	1.45	2	6.34
3	351 to 600	3.46+7.43+10.32	0.2	1.45	3	7.62
4	More than 600	3.46+7.43+10.32+11.71	0.2	1.45	4	8.65

With these basic rates the energy tariff for the slots said above can be calculated keeping basic rate constant the coefficients for each category of period is calculated as

$$\frac{R_P + R_F + R_V}{3} = R_b \qquad (6)$$

$$\frac{(a \times R_b) + (b \times R_b) + (c \times R_b)}{3} = R_b \qquad (7)$$

Were,

energy rate for peak period $R_P = a \times R_b$, (8)

energy rate for flat period $R_F = b \times R_b$, (9)

energy rate for valley period $R_V = c \times R_b$ (10)

Assuming a=1.5, b=1.0 and c=0.5 the energy rate is determined for peak, flat and valley period as tabulated below.

Table 4 Proposed dynamic price rate

Sr. No.	Consumption Slab	Basic rate per unit R_b in ₹.	Energy Charges for peak period R_P in ₹. $R_P = a \times R_b$	Energy Charges for flat period R_F in ₹. $R_F = b \times R_b$	Energy Charges for valley period R_V in ₹. $R_V = c \times R_b$
1	Less than 150 units	5.57	6.13	5.85	4.73
2	151 to 350	6.34	6.97	6.65	5.38
3	351 to 600	7.62	8.38	8.00	6.48
4	More than 600	8.65	9.51	9.07	7.35

The fuel adjustment charges will be applicable as per the present tariff.

It is assumed that the consumer is utilizing more than 70 % load in the peak period and the remaining load in the off-peak period. For reduction in peak curve if any consumer shifts at least 20 % load the consumer will have a reduction in energy amount and if the pattern is the same as present the energy amount increases as per present, this may be an identification for the consumer to shift the load.

5. Result and Discussion

The inclusion of multiple tariffs in the energy meter will give the flexibility to choose tariffs according to the use. This will have a softness for the consumer to manage the consumption of electricity according to the charges applied, which will reduce energy charges.

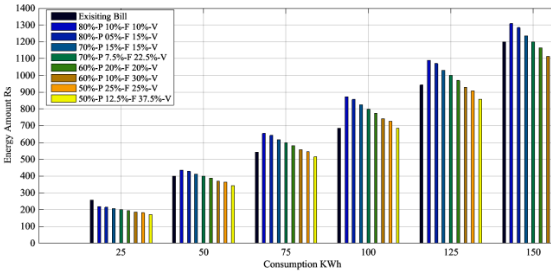

Fig 2(a) Energy charge reduction for Slab 1

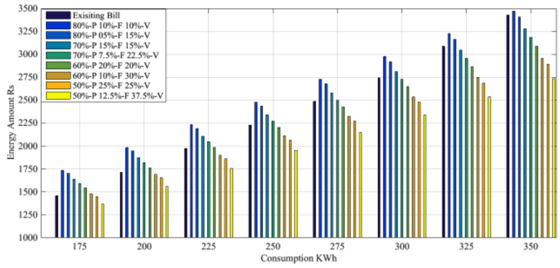

Fig 2(b) Energy charge reduction for Slab 2

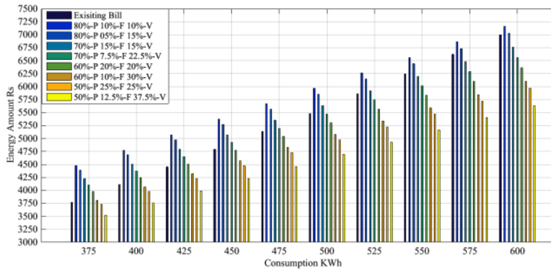

Fig 2(c) Energy charge reduction for Slab 3

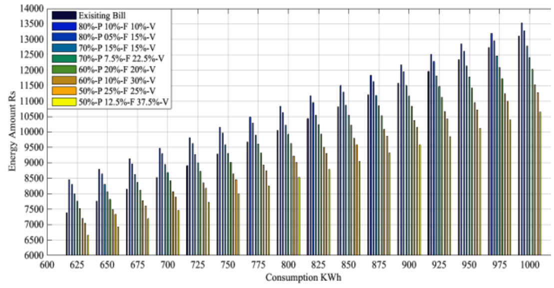

Fig 2(d) Energy charge reduction for Slab 4

From fig 2(a) to 2(d), it can be seen that from the consumer's side utilizing fifty percent load in peak hours and remaining used in flat and valley period there will be definite saving in energy cost. Particularly the savings will be significant if the maximum from the remaining load is switched in the valley period. The saving observed is from Rs. 28 to 2457 for availing load fifty percent in peak period and other load is switched in flat and valley period. On the other hand, considering 20 % load has shifted by the residential consumer which reduces the burden on residential feeder resulting into reduction in line loss. Also, the saved units from the residential consumer are diverted to the other consumer where the energy rates are higher compared to the residential tariff. Hence by offering this dynamic pricing utility and consumers both can satisfied.

6. Conclusions:

Electricity rates available depending on the time of day will encourage consumers to use electrical appliances at lower rates instead of at higher rates, which will help in reducing the gap between power generation and demand. The smart energy meter is also developed with an idea to protect from theft of electrical energy by the residential consumer. The theft can be done by bypassing of energy meter, tampering, some consumers are utilizing energy more than their sanctioned load. The theft detection is achieved with the help of two current transformers connected at the end of the service wire. With the help of a tactile sensor, tampering is detected. The overloading is indicated with the use of current sensed by the current transformer. In the proposed system whenever any mischief is detected, at the same time text message will send to the utility as well as the consumer. In this meter, the facility of detecting theft, tampering with the meter, bypassing the meter, using more than the approved electrical load, will help the electric power industry to recover the theft, as well as the cost of production, transmission, and distribution from the customers.

The proposed system has some following advantages

1. Cost-Effective Energy meter system
2. Could be beneficial to increase government revenue.
3. Overload detection will help to protect transmission transformers.
4. Variable tariff rates can be used for different types of users at different load conditions.
5. Antitheft system helps in preventing electricity theft.

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