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Research Article

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Non-cooperative game theory based stepwise power tariff model using Monte-Carle simulation for agricultural consumers

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Abstract: In the present study the concept of non-cooperative game theory is proposed in the retail electricity market for introducing stepwise power tariff model (SPT) for agricultural consumers. The objective of the paper is to increase the energy generation through green energy generation sources (GEGS), introduction of plug-in hybrid electric vehicles, education of families, standard wiring and appliance efficiency in tariffs for agricultural consumers with non-cooperative game theory. Agricultural consumers are able to generate a huge amount of electricity through GEGS and are able to control the consumption in their own way, and the non-cooperative game theory is introduced. Energy consumption pattern varies with respect to time during off-peak load period to peak load period; during the peak load period the demand is high as compared to off peak load hour duration energy consumption for the consumers and policy makers interrupting the energy supply during peak hours for agricultural consumers. To maintain the balance between generation and consumption, energy saving is essentially required and needs to maintain the consumption patterns and increase the penetration level of distributed generation at the agricultural consumer end due to availability of land. This paper proposes an algorithm for a demand response methodology using SPT with non-cooperative game theory model based on monthly energy consumption to maintain the balance. The uncertainty about energy generation through GEGS taken in consideration using Monte-Carlo simulation (MCS). Simulation results obtained by the proposed methodology are compared with the conventional methodology of energy tariff used in India and provide better results for active consumers and generate a considerable amount of electricity through GEGS.

Keywords: Green energy generation sources; Plug-in hybrid electric vehicles; Stepwise power tariff model; Non-cooperative game theory; Retail electricity market.

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Nomenclatures

Acronyms

DER's	distributed energy resources
DSM	demand side management
MCS	Monte-Carlo simulation
SPT	stepwise power tariff
GEGS	green energy generation sources

Sets & indices

m	number of agricultural consumers
T	time set for energy consumption
Ta	time set of appliance on-off duration
Tg	time set for green energy source
α_G	on state of GEGS
β_G	off state of GEGS
a	appliance connected at consumer end
η	efficiency of equipment

Parameters

E_a	energy consumed by appliance a
$E_{T,a}$	energy consumed by appliance a at particular time frame
E_T^m	total energy consumption of mth consumer
Za	energy brought and injected into grid
V(S)	value of action defined energy generation
χ	weather factor of energy generation
$w_{T_g}^G$	wattage of GEGS
Q_I^π	incentive factor provided to consumers

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Q_T^{η}	average efficiency of agricultural consumers
w_T^{η}	wattage for efficiency of equipment
w^f	wiring factor for consumers
Q_T^{η}	binary number denoted wiring certification
$w_T^{w_c}$	wattage of wiring factor
Q_T^{fm}	number of family members
w_T^{fm}	wattage of number of family members
Q_j^{ed}	education slab
w^{ed}	wattage of education factor
$p(m_i\|m_{-i})$	probability of i^{th} consumer
$C_i(m_i)$	payoff function of consumers
$x_c(m_i)$	wattage of constraints
$C_i(m_i^*)$	best response of payoff function

1 Introduction

Dependency on electricity in terms of industrial, commercial, household and agricultural loads are increasing day by day. All categorized loads are supplied through electrical grids and the dominant amount of electricity is generated through fossil fuels at cheap cost but emit greenhouse gasses into the atmosphere. Other critical concerns are energy shortage, energy security, climate change etc. which are resolved by energy saving in a smart grid environment (Diamantoulakis et al. 2016; Singh et al. 2013, 2014a). Introduction of distributed energy resources (DERs) in power systems will reduce the green-house gas emission but bring up some giant challenges in the near future e.g. power imbalance and power quality issues (Singh et al. 2014b, 2010a). These challenges are essentially related to the periodical nature of DERs, and an alternative to cope these challenges are demand side management (DSM). DERs are the renewable energy sources installed near the load centers to reduce the transmission and distribution losses and provide environmental friendly electricity to consumers at low costs. All the categorized loads consume electricity in their own way and produce variable patterns of consumption. The cluster of the consumption is determined allowing introduction of peak hours where the energy cost is higher. Some of the consumers are cultivating plants for the primary fulfilment of humans categorized as agricultural consumers. Beyond primary food, agricultural consumers produce a vast variety of agricultural products from their cultivars in the form of clothes, papers, decorative flowers, ethanol etc. (Baourakis et al. 2002). Agricultural consumers require a suitable amount of electricity from the utility for production of goods. Energy generation is lower as compared to consumption and drastically affects the energy supply duration to consumers.

Demand side management is essential for energy balance and with storage units provides a solution for the smart grid environment. In future, electric grid consumers will be able to interact with utilities and on the basis of their communication, demand will be shifted (Singh et al. 2010b, 2011). Smart grid manage the demand and provide two-way energy flow from the utility to the consumer, as well as the consumer to the utility with the help of intelligent electronic appliances (Yuan et al. 2017). Agricultural consumers with availability of a large land space establishing DERs have a great potential with the implementation of DSM.

To manage the demand, agricultural consumers have to manage their appliance operations. Scheduling of appliance operations is managed by providing incentives to the consumers. Several energy tariff models are present in the literature. Some of these are two part tariffs, time of use, stepwise power tariff, real time pricing etc. Two part tariffs divide monthly energy consumption into two parts. First there is energy consumption, and secondly capacity price (Ji and Yang 2009). Real time pricing with intelligent electronic appliances conveys the message of energy price on a real time basis and consumers manage their demand from high cost to low cost energy price duration (Lin and Liu 2013). Time of use divides the appliances into two categories on the basis of operation fixed appliances and manageable appliances. Fixed appliances e.g. light, refrigerators etc. are not manageable but manageable appliances e.g. air conditioners, heaters, boilers are providing comfort to the consumers and their operation duration as well as their operation timing is manageable (Yang et al 2013). The stepwise power tariff (SPT) model divides the consumption into various slabs on the basis of defined constraints and a different premium is decided for individual consumption slabs (Canbing et al. 2013). Consumers want to get the maximum benefit, and they may shift their appliances as per defined constraints to get maximum benefit provided by reduction in utility benefits. The game theory approach is introduced to provide a suitable solution.

Game theory is a mathematical tool to optimize the problem of sharing benefits on the basis of a defined set of rules. Some of game theory approaches provide solutions by a group of consumers and are called cooperative game theory, and some provide solutions for a particular consumer and are known as non-cooperative game theory

(Talwariya et al. 2016). A considerable literature is present on game theory based demand side management for residential/household consumers (Yanpeng 2016; Marzband et al. 2016). Agricultural consumers have had the attention of very little research. The following shortcomings relative to demand side management apply for the new tariff based on the SPT model:

– Most of the researchers adopted different methodologies of DSM with household consumers and agricultural consumers getting very little attention.
– Most of the methods operated on real time pricing, having a large gap in terms of monthly energy tariffs.
– No method explored the resources of DERs or electric vehicles for agricultural consumers for efficient operation.
– Improving the efficiency at the consumer end, efficient appliances and standardization of electric wiring was not taken into consideration.
– Education as a constraint for effective tariffs has not been considered.

The objective of the paper is "to introduce an advanced tariff strategy for agricultural consumers with the help of non-cooperative game theory model optimized on stepwise power tariff model constraints to find a nash equilibrium between agriculture consumer and energy utility". A non-cooperative game theory model with constraints e.g. green energy generation sources, plug-in hybrid electric vehicles, efficient equipment, education of family, income tax return, etc. focused on each consumer benefit. A set of data of scheduled energy consumption is required to test the proposed methodology which is generated by Monte-Carlo simulation (MCS). MCS is a mathematical tool to generate random sets of data to optimize the probability and statistical analysis. This method is beneficial for the consumers if they actively participate in the form of incentives and the consumer who does not actively participate will pay a higher payment which is the drawback of the consumer having a lack of awareness. The major contribution of the research paper can be listed as following:

– Increasing the energy generation from green energy generation sources by agricultural consumers having availability of land space for installation.
– The retail electricity market using game theory within the constraints of an SPT model providing benefits to active consumers.
– A demand side management algorithm is developing for novel constraints of the SPT model.
– A win-win situation is obtained by finding nash equilibrium between consumers and utility for participation.

Constraints of a new SPT with non-cooperative game theory is designed with a view to increasing the penetration level of GEGS. European nations set a target to generate 20% electricity through renewable energy sources and increase the share of electric vehicles to 10% by 2020 reported in action plan of European commission 2012 (http://ec.europa.eu/transport/themes/urban/urban_mobility/doc/com_200490_5_action_plan_on_urban_mobility.pdf - 2012). India is targeting to generate 175 MW of electricity by 2030 through GEGS. On 23 April 2009, the Parliament of European Council prepared a "promotion of GEGS and efficient road transport through vehicles" action plan to prepare agricultural consumers to increase the generation through GEGS (IEA 2013). The electric vehicles initiative is taken up by 15 countries from Asia, Europe, Africa and North America and has set a target to sell 20 million electric vehicles worldwide, which effectively reduces the air and noise pollution in environment (Wu et al. 2017). Standard wires and efficient appliances are already available in existing systems allowing governments to try to increase the number of consumers. Education is important to educate the farmers about their benefits and to make them aware about government schemes for their improvement. Many agricultural tools are available to increase the growth rate of cultivating and other agricultural products. Education also ensures the consumers maintain their appliances in order to maximize their payoffs.

The rest of the paper is organized as follows: generation of a large set of Monte-Carlo simulation data is explained in section 2; mathematical modeling of defined constraints are in section 3. Section 4 represents the stepwise power tariff model with a non-cooperative game theory model with the help of an algorithm. Results of peak hour duration and normal hour duration and a comparative study with existing systems are shown section 5 and the conclusion is in section 6.

2 Monte-Carlo Simulation

Monte-carle simulation (MCS) is an advanced mathematical tool for testing probability and statistical problems of desired outcomes with the help of a generated set of random inputs (Wang and Infield 2018). MCS performed risk analysis by generating models of possible outcomes by considering a suitable range of values for probability distribution of inherent uncertainty. The MCS then calculates the results again and again using different sets of randomly generated values depending upon uncertainties within a specified range. Thousands of repetitions are taken by MCS to generate random sets of values of energy consumption before compilations. A large set of energy consumption data is required to simulate the SPT model with game theory which is generated through an MCS tool taking into consideration random characteristics of consumers. Green energy generation sources of energy generation are variable and depend upon weather parameters, which are taken into consideration in the MCS method. A set of energy consumption by agriculture consumers is generated on the basis of the following assumptions:

- Normal and peak hour energy consumption is defined for agricultural consumers, taking into consideration for energy demand.
- A major part of energy is supplied to agricultural consumers during normal hours by the utility in India.
- Energy consumption during normal hours and peak hours are taking half of the duration for agricultural consumers (Central Electricity Authority 2017).

Monte-Carlo simulation randomly generates the inputs defined by the set M and then applying on m ∈ M. a = 1,2,3……. is the number of appliances connected at the consumer end. Appliances are in two states on and off; on state being defined as one and the off state is defined as zero. The appliance's on-off duration is defined as Ta. Energy Consumption of particular equipment is defined in (1) and for all consumers in (2):

$$E_{T,a} = E_a \times T_a \quad (1)$$

$$E_T^m = \text{rand} \times Ta \times E_{T,a} \quad (2)$$

Where, E_T^m is the random energy consumption of the m^{th} consumer for normal and peak hour duration as generated by a random set of data for M number of consumers.

3 Mathematical modelling of constraints

New constraints are designed and recommended in stepwise power tariff models to enhance the generation capacity as well as reduce the losses in transmission and distribution.

3.1 Green Energy Generation Sources (GEGS)

The majority of electricity is generated from fossil fuels which affects the environment. Green energy generation sources (e.g. hydro generation, wind turbines, solar photovoltaic cells etc.) provide a solution (Singh R. et al. 2009). According to central electricity authority report January 2017 total energy generation from renewable energy sources are 45,916.95 MW. India has a huge potential for green energy sources and if consumers get benefits for installing green energy sources, penetration levels of green energy sources will be enhanced. India is targeting to generate 175 MW of electricity from renewable energy sources by 2030 and will only achieve this by the involvement of agricultural consumers. Agricultural consumers have enough land space to develop a considerable amount of energy from solar photovoltaic and wind energy sources. Agricultural consumers are using local green energy sources (GES) and generate electricity; $\pi_{T\,g}^{G}$ for each time slot T_g for normal and peak hours in (3).

$$Z_a = (P_{T_g}^{a} - \pi_{T_g}^{G}) \quad (3)$$

Z_a is defined as the energy brought and injected into the grid by GEGS, Z_a is negative when energy is injected into the grid during normal hours and positive if generation is lower than consumption during peak hours.

$$\alpha_G \le T_g \le \beta_G \quad (4)$$

In (4), (α_G, β_G) Denotes the turn on and turn off states of GEGS and $\pi_{T\,g}^{G}$ is the total energy generation from green energy sources. At α_G the total energy generation is zero at initial stage. T_g is the duration when energy is generated from green energy sources and an incentive is provided to consumers for the supply access amount of electricity to the grid. If incentives are non-deterministic, in which the future state is randomly generated and the consumer always get some incentive I for any GEGS G, $V(G)$ is defined as the value of action defined by energy generation type G e.g. solar wind etc. in (5).

(5)

$$\begin{cases} V(G) = 0 & \forall\, T_g < \alpha_G \text{ for all A.} \\ V(G) = 1 & \forall\, \alpha_G \le T_g \le \beta_G \text{ for all A at a particular duration } T_g. \end{cases}$$

Consumers will get maximum benefits for generating the maximum amount of electricity from GEGS in (6) having the function containing the generation factor, incentives of the consumers and value of action.

(6)

$$\max_{s} V(G) = V(G) + \chi[I_{t+1}(G) - V(G)] \quad \forall\, I_{t+1}(G) \in I \text{ for next step of generation}$$

Where, χ is denoted as the energy generation factor depending upon weather conditions. The infinite-horizon model of the system is required, and not having any sequence limit, rewards will be given on the basis of assuming the estimation of generation in the next step in

$$w^{G}_{T_g} = \begin{cases} P^{a}_{T_n} \text{ X } Q^{\pi}_{I} \text{ X } (Z_a - \pi^{G}_{T_n}) & \forall \text{ normal hour load} \\ P^{a}_{T_p} \text{ X } Q^{\pi}_{I} \text{ X } (Z_a - \pi^{G}_{T_p}) & \forall \text{ peak hour load} \end{cases} \quad (7)$$

Where, $w^{G}_{T_g}$ defines the wattage in the tariff for generating electricity from green energy sources and, Q^{π}_{I} is the factor of incentive provided to consumers by assuming the generation patterns one day ahead.

3.2 Efficiency of equipment

Large electric motors are required by agricultural consumers to pump the water. If they use less efficient appliances, huge amounts of energy are wasted as losses. Efficiency of equipment is defined between one to five by manufacturers. One denotes the least efficient appliances and five for most efficient appliances (Singh N. and Kumar A. 2014). Less efficient appliances are cheaper in cost, and to move the consumers from less efficient to more efficient appliances needs incentives to be provided to consumers.

Connected appliances $a \in A$ have different efficiencies. The average efficiencies of categorized load are in (8):

$$Q^{\eta}_{T} = \sum_{\eta=1}^{5} A^{\eta}_{T} \quad (8)$$

Wattage for the efficiency of equipment is defined by w^{η}_{T} for a particular duration T in (9).

$$Q^{\eta}_{T} = \sum_{\eta=1}^{5} A^{\eta}_{T} \quad (9)$$

3.3 Wiring Certification

The national electricity code and ISI standard provide standardization on wiring used to connect appliances. Consumers are not appraised for the losses generate by inefficient wires, resulting in lost energy. Wiring certification Q^{w}_{T} is taken as binary number which is denoted as one for certified consumers and zero for non-certified consumers in (10).

$$w^{w_c}_{T} = \sum_{s} P^{a}_{T} \text{ X } (w^{f} - Q^{\eta}_{T}) \quad (10)$$

In (10), $w^{w_c}_{T}$ is denoted as the summation of wiring wattage used in tariffs for agricultural consumers for all connected appliances and w^{f} denotes the wiring factor for consumers.

3.4 Electric vehicles

Transportation is important for all the categorized consumers especially for agricultural consumers, who need to send their vegetable/fruits to market to be sold. Initial cost of plug-in hybrid electric vehicles are higher as compared to conventional vehicles but their environment friendly ability gets attention and needs motivation for all kind of consumers. The wattage factor is defined as positive one for consumer who do not have plug-in hybrid electric vehicles, and higher tariff rates. The wattage factor is defined as negative one for active consumers having plug-in hybrid electric vehicles, who get incentives as a proposed tariff strategy.

3.5 Number of family members

Energy consumption is directly proportional to the number of family members. This factor divides the energy consumption into a number of slots in normal and peak hours. Energy consumption charges are minimal for the lower energy consumption slab and increase with consumption slab to the same as the conventional tariff. The energy consumption factor is defined as Q^{Fm}_{T} and wattage of the constraint number of family members is defined in (11):

$$w^{fm}_{T} = \sum_{m} P^{A}_{T} \text{ X } Q^{fm}_{T} \quad (11)$$

3.6 Education of family

Education is the right of each stake holder of the country. Especially in India education becomes the major role in national growth as a developing country (MHRD 2016; Thomas 2003). Agricultural consumers are least attentive towards education and the factor provides an incentive which will motivate toward education. Every stake holder has a different education level and a mean of family education is taken (for stake holders aged more than 25 years) Here j is the person from agricultural set of consumers $j \in J \in N$. and wattage of education constraint is taken by (12):

$$w^{ed} = \left(\sum_{j} Q^{ed}_{j}\right) / J \quad (12)$$

J denotes the number of family members more than 25 years and makes an assumption that a person is highly educated by the age of 25 years. In (12) Q_j^{ed} is denoted as the education factor depending upon the qualification slab.

4 Non-cooperative game theory model for stepwise power tariff

Non-cooperative game theory is applied to maximize the benefits of individual consumers on the basis of following assumptions:

- Each consumer has intelligent electronic appliances (e.g. smart meters, inverters, storage controllers etc.).
- Consumers actively participated to enhance their benefits in the form of incentive in tariff.

Each defined constraint is provided a probability and on the basis of these probabilities a function is calculated of the energy consumption cost. Conditional probability of $m \in M$ is $p(m_i|m_{-i})$ where $m_{-i} = (m_1, \ldots, m_{i-1}, m_{i+1}, \ldots, M_i)$ is the combination of all consumers except the i^{th} consumer from the set of M in (13).

$$p(m_i|m_{-i}) = \frac{p(m_{-i,}m_i)}{\sum p(m_i)} \quad (13)$$

Payoff function for the i^{th} for consumer agriculture consumers can be expressed by (14):

$$Ci\ (mi) = \sum_{m_i \in M_i} (p(m_i\ |m_{-i}, x_c) x_c(m_i)) p(m_i|m_{-i}) \quad (14)$$

In (14), $x_c(m_i)$ denotes the wattage of constraint for the agricultural consumer. Every consumer enhancing the payoffs by applying the best strategy and maximizes the benefits. A nash equilibrium is calculated between consumer and utility, and the maximum payoff function is $C_i(m_i^*)$ is defined in (15).

$$C_i(m_i^*) \geq Ci\ (mi) \quad (15)$$

Once the equilibrium is found the maximum payoff for all the consumers of different categorized loads are evaluated to provide maximum benefit to the consumers (Talwariya et al. 2019).

Algorithm:

```
Input: Initialize set of categorized loads, Electricity Consumption/hour, constraints modelling
Output: Nash equilibrium for all categorized consumers.
Initialization: the wattage x_c(m_i) of all categorized loads.
Repeat:
        m =1;
        for m ≤ M Do
            i=1;
        while i ≤ I Do
            update the strategy on the basis of M category
            for every consumer by Ci(mi*).
            i=i+1;
        end
                m=m+1;
        end
        Until nash equilibrium obtained.
Return x_c^*(m_i)   for i ∈ I and m ∈ M.
Result
```

Ethical approval: The conducted research is not related to either human or animal use.

5 Results

The non-cooperative game theory based stepwise power tariff model generates results in the form of normal and peak hour generation. Results are verified by comparing with the existing system used by Jaipur Vidjut Vitran Nigam Limited (JVVNL 2016). For agricultural consumers the energy utility is charged at a flat rate tariff. A case study on 100 agricultural consumers, used data generated through Monte-Carlo simulation. The proposed approach provided the energy consumption tariff based on defined constraints which are beneficial for consumers as well as utilities. Normal and peak hour consumption tariffs were

Table 1: Comparative study of normal and peak hour energy tariff

Time Duration	Normal Hourly Duration	Peak Hourly Duration
Maximum Tariff (Rs/month)	106.91	431.78
Minimum Tariff (Rs/month)	0.056	4.46
Mean Tariff (Rs/month)	55.90	196.51
Total Tariff (Rs/month)	5589.84	19651.03

Table 2: Comparative study of SPT-GT model and conventional model of energy tariff

Tariff Model	SPT-GT Model	Conventional Model
Maximum Tariff (Rs/month)	498.33	669.19
Minimum Tariff (Rs/month)	11.08	71.73
Mean Tariff (Rs/month)	252.48	381.58
Total Tariff (Rs/month)	25248.35	38157.56

evaluated separately Figure 1. This shows the normal hourly energy consumption where, the cost of energy consumption as Rs/month varies from 0.5 to 106.91 Rs/month. Figure 1 shows the peak hour energy consumption cost when the tariff charges are higher varied between 4.65 to 431.78 Rs/month as defined in Table 1.

Total energy consumption cost by summation of normal hour consumption and peak hour consumption is calculated and compared with the conventional tariff model. Figure 2 shows that for most of the consumers the proposed model cost is less as compared to the conventional model tariff. The proposed model energy consumption tariff varied between 11.08 to 498.33 Rs/month and comparatively for conventional model the tariff cost varied from 71.73 to 669.19 Rs/month as defined in Table 2.

6 Conclusion

Energy is essential for agricultural consumers to irrigate land and to grow produce on their farms. In the existing system, agricultural consumers have to pay fixed amount of charges to the utility without depending upon their consumption. The proposed model of stepwise power tariffs using a non-cooperative game theory model provides better solution and benefits for agricultural consumers. A case study of 100 agricultural consumers provided results during normal hours, peak hours and compared tariffs with conventional methods of producing energy tariffs. As simulation results show, during normal hours the energy consumption cost is less as compared to peak hours as shown in Table 1. Table 2 compared the results with previous methods of producing energy tariffs used in India showed that the maximum tariff is reduced from 669.19 Rs/month to 498.33 Rs/month for particular consumers consuming maximum energy. The minimum tariff is reduced from 71.73 Rs/month to 11.08 Rs/month for the lowest energy consumption consumers. The total tariff is reduced from 38,157.56 Rs/month to 25,248.35 Rs/month provides a total benefit of 12,909.21 Rs/month to agricultural consumers. The proposed model is beneficial for consumers in terms of the relaxation provided in terms of tariff and utility and is benefitted with the availability of GEGS and electric vehicles as storage units provides a win-win situation between consumer and utility.

Conflict of interest: Authors declare no conflict of interest.

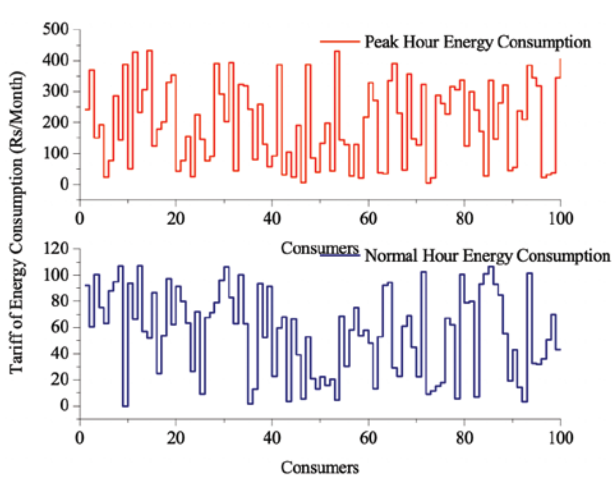

Figure 1: Agricultural consumers Energy Consumption during normal hours and peak hours

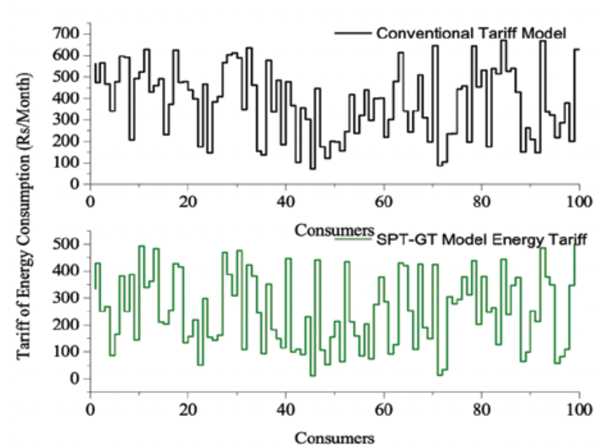

Figure 2: Comparative Electricity Tariff of SPT-GT model and Conventional Model for Agricultural consumers

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