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Research Article

MODELING AND IMPLEMENTATION OF TIM OF USE DEMAND RESPONSE PROGRAM TO THE IRAINIAN CONSUMERS WITH CONSIDERING UNCERTAIN PRICE ELASTICITY

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ABSTRACT
Nowadays power companies more and more tend to implement methods of demand response among their customers. These methods are divided from demand side management methods that can generate several benefits including reducing production cost, system peak, consumer's bills as well as reliability enhancement. System operators are seeking to fore cast their customer's response to these methods but uncertain behavior of subscribers will lead to its complexity. In this paper a mathematical model is introduced to predict the behavior of customers with regard to uncertain price elasticity of them. In this model is used from normal probability distribution function and also the modern is used for simulating customers, behavior in response to the time of use program as the most prevalent program. Finally the present time of use demand response program for domestic consumers in Iran has been implemented by this present model and technically and economically is evaluated. The results indicate some advantages and disadvantages of the time of use program which is employed for Iranian customers. And also they could have some useful ideas for demand response program designers.

Keywords: *Probability Density Function of a Normal Distribution- Demand Response – Time of use- uncertainty*

List of Symbols and Abbreviations
O: Initial situation Index
$\Delta\rho$: Electricity tariff change

$B[d_t]$: Customers profit by taking dt at time
$t, \acute{t}$: Time Index
e_{tt}: self price elasticity
$e_{t\acute{t}}$:Cross- price elasticities
Nd : Number of divisions of the normal probability density distribution function
Nt: Number of time
$e_{tt,i}$: Self price elasticity of i^{th} segment from
$e_{t\acute{t},\acute{\imath}}$: Probability density distribution function
d : Demand
Δd: Study case
ρ : Electricity tariff
$prob_i$: cross- Price elasticity of i^{th} piece of probability density distribution function Demand change probability of i^{th} segment from customers.
η : Potential for implementation of demand response (percent)
μ :the mean value of normal probability density distribution
σ :the standard deviation of probability density function of normal distribution.

INTRODUCTION
Demand response is defined voluntary changes of consumption in response to incentive policies or electricity price change when wholesale prices are too high or system is at risk. In the other hands, load reaction will mean that consumers have sufficient incentive to reduce their demand when electricity price are high and the system is at risk.

According to the U.S Department of Energy, demand response is divided to two categories: price – based and incentive – based methods (see figure1). Price – based methods had been emerged from the first days of electricity industry and until now they have been developed in different to designs and while incentive – based method (except direct load control or by different ways intractable load in combination with restructuring electricity industry structure with other methods have been proposed to electricity consumer. As yet considerable researches have been done to mode demand response programs. The researchers are based on maximizing benefits from consumption of electricity, using benefit function of consumers. The main mathematical medals in demand response are liner l logarithmic exponential and potential that liner model has been used for simulating some methods in demand response. In fact, this simple model represents a liveried function of demand at an operation point.
In this paper the potential model is considered. This model the first time in (Schweppe *et al.*, 1985; Baldick *et al.*, 1992) was examined. The mentioned model is sufficiently according load characteristics, including being concave and descending (in contrast with Liner model). The most serious criticism of the models presented in published research is that fixed price elasticity has been considered. While cannot be considered customers behavior only with a given amount as elasticity. In this paper has been investigated the uncertain elasticity and it has been included in the model. The model presented is adjusted for maximizing consumer's behavior in response to Tou program in accordance with terms of implementation between Iranian domestic consumers.
In sections2 is presented price – elasticity and in section 3 considering uncertainty in this parameter. In section is presented proposed model and in section 5 desired demand response briefly is introduced. In sections simulation results and after that conclusions are presented in 7.

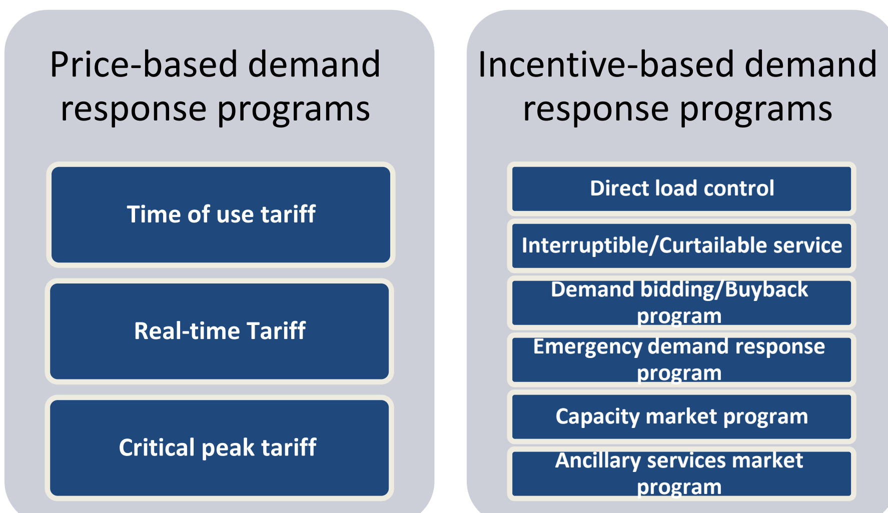

Figure 1: Demand response methods categories

1. Demand Price Elasticity Definition

Generally electricity consumption like the other goods depends on its price. It means that increase of the price leads to reduce the consumption and vice versa. Based on economics theory price elasticity is introduced as follows (11).

$$e = \frac{\Delta d / d}{\Delta \rho / \rho} \qquad (1)$$

Considering different hourly demand it can model hourly tariff change effect on load in each hour using the same meaning. Hence we have two demand price elasticity: e_{tt} owned elasticity that indicates the effect of fined price changes in time t on electricity consumption, at the same time, with positive values.
Equations 2 and 3 represent the mathematical concepts (2) (3).

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$$e_{tt} = \frac{\partial d_t / d_t}{\partial \rho_t / \rho_t} \quad \textbf{(2)}$$

$$e_{t\acute{t}} = \frac{\partial d_t / d_t}{\partial \rho_{\acute{t}} / \rho_{\acute{t}}} \quad \textbf{(3)}$$

2. Uncertain Price Elasticity
Probability density function of normal distribution is as follows

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} exp\left[\frac{-(x-\mu)^2}{2\sigma^2}\right] \quad \textbf{(4)}$$

That μ is the mean and σ is the standard deviation. Normal distribution with mean μ and three different standard deviations are shown in figure 2. As it is indicated the amount of standard deviation determines the horizontal tallness of normal distribution. In fact considering more uncertainty in a parameter is modeled by larger standard deviation values.

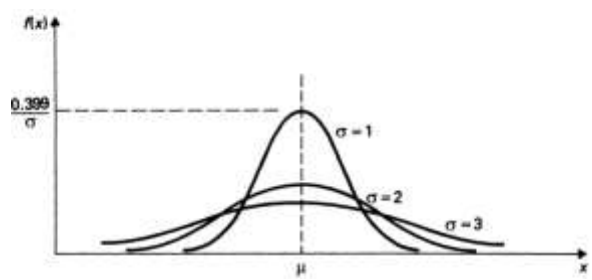

Figure 2: Probability density function of normal distribution for three values

As mentioned in the introduction, in modeling that has dons elasticity is a definite parameter. While with complexity of customers behavior, it should be extracted the probability distribution function from consumer's data and that is a difficult task.
In most of published researches normal distribution function is used for showing uncertainty in elasticity. For this purpose, the mean of normal distribution is considered as the expected value of elasticity. Normal distribution function can be divided in to several intervals, 3, 5, 7 and so on. Probability of occurrence of the midpoint of any interval is considered equal to cumulative probability of that interval of normal distribution. For example, normal distribution function is divided into 7 intervals and probability related to the midpoint of each interval is listed above it.

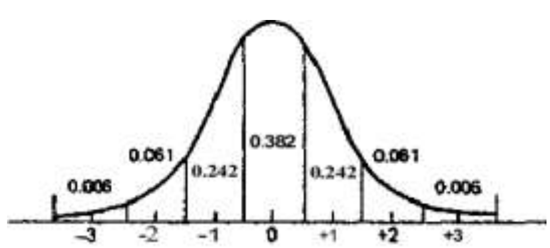

Figure 3: Normal distribution function approximation of 7 intervals

4- Demand Response Modeling
According to equations (2) and (3) we have:

$$\frac{\partial d_t}{d_t} = e_{t\acute{t}} \frac{\partial \rho_{\acute{t}}}{\rho_{\acute{t}}}$$

Assuming a constant elasticity value predicated for NT and integrating over study case period, we have:

$$\int_{d_t^0}^{d_t} \frac{\partial d_t}{d_t} = \sum_{\acute{t}=1}^{NT} \left\{ e_{t\acute{t}} \left[\int_{\rho_{\acute{t}}^0}^{\rho_t} \frac{\partial \rho_{\acute{t}}}{\rho_{\acute{t}}} \right] \right\} \quad \textbf{(5)}$$

Equation (6) shows consumer behavior, i. e demand response mathematical model.

$$d_t = d_t^0 \prod_{\acute{t}=1}^{NT} \left(\frac{\rho_{\acute{t}}}{\rho_{\acute{t}}^0} \right)^{e_{t\acute{t}}} \quad (6)$$

Parameter η indicates the customer potential (percent) for implementation of demand response and it shows the will mgness of greater number of customers to participate in demand response program. This parameter is considered as follows:

$$d_t = d_t^0 + \eta d_t^0 \left\{ \prod_{\acute{t}=1}^{NT} \left(\frac{\rho_{\acute{t}}}{\rho_{\acute{t}}^0} \right)^{e_{t\acute{t}}} - 1 \right\} \quad (7)$$

Section 3 describes how to consider elasticity uncertainty based on normal probability distribution function. So, considering ND intervals in normal distribution function, demand response model will be as follow.

$$d_t = \sum_{i=1}^{ND} \left[prob_i \left(d_t^0 + \eta d_t^0 \left(\prod_{\acute{t}=1}^{NT} \left(\frac{\rho_{\acute{t}}}{\rho_{\acute{t}}^0} \right)^{e_{t\acute{t}},i} - 1 \right) \right) \right] \quad (8)$$

Where, $prob_i$ is the probability of i[th] interval in normal distribution function and $e_{t\acute{t},\iota}$ is the midpoint of i[th] interval.

5 Time of Use

TOU is the most common method. This method encourage consumers to improve consumption pattern, i.e. consuming electricity in unpeak times and reducing consumption in peak times, with changing in tariff of different times. According to economics, the proper way for encourage consumers to reduce their consumption is informing them about real price of market and charging them with these prices when they are consuming electricity. But price change in the market is accidently It is clear that the majority of consumers don't have enough time and equipment for knowledge instanceous changes in price that's, use of several intervals in a day for applying electricity tariffs to this group of consumers is useful.

Typically, in Tou method, three tariffs are determined for three periods of a day that are peak, low and of peak periods. Each tariff is the average of actual electricity price within each period. Also Tou tariffs may be calculated for different times of day or days of week or time of year. In other hand, these tariffs can be daily or seasonal. And usually are predicted for several months or years.

Price (Rial /kwh)

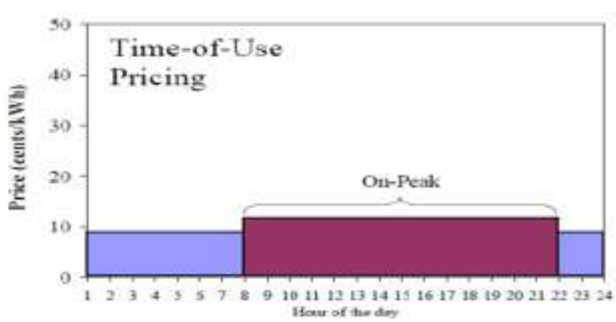

Figure 4: Example of daily Tou tariffs

Necessity for participating in Tou, is equipping with measuring instrument with ability to record consumption value in each interval. Traditional and remote measurement instruments are not proper for these methods but advances in measurement technology toward AMI provide the desired condition for implementation of such programs.

Subscribers of the program are large industrial and commercial consumers that extensively participate in such programs. In domestic sector using these tariffs results in having smoother load profile through reducing consumption in period with high price and increasing consumption in periods with lower price.

In these methods, time intervals and electricity price in each interval in different distribution company are different due to their peak load in day, season and year. Figure4 represents example of daily Tou tariffs. In next section, this method is considered and investigated among electricity customers in domestic sector.

6. Simulation Results

In this section, it is used from demand data of Iran electricity network. For this purpose, the data is selected from August 6th 2014. The demand curve is shown in figure 5.

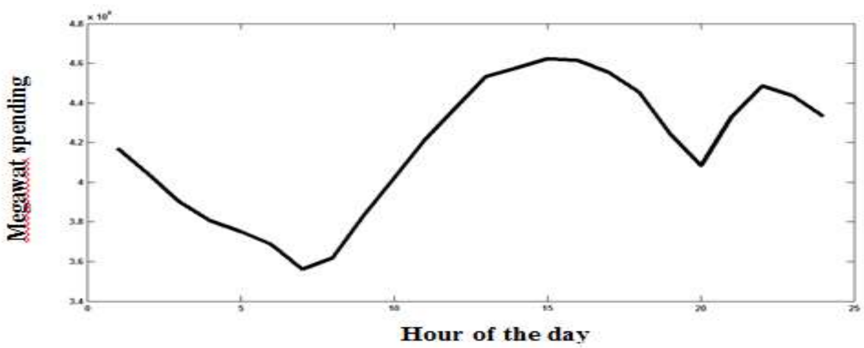

Figure 5: The data is selected from August 6th 2014

In Iran scheduling of Tou is divided into two six-month intervals. The details are shown in Table 2 [13]. Note that in these periods the hours related to peak, off peak and load time periods are fixed. The study is performed in first half a year on peak day. Considering of load cure in figure 5 and comparing load in off – peak hours and peak time, it is appeared that peak time has not been accuracy defined. And defining only two six – month periods to schedule is not sufficient.

Table 2: TOU scheduling in Iran

Two six – month	One six – month	Period
From 5 to 17	From 8 to 20	Off-peak
From 17 to 21	From 20 to 24	peak
From 21 to 5	From 24 to 8	Low load

At present, using smart metering infrastructure, demand response is running in Iran. In these meters can be determined different tariffs for different times that customer bills are calculated based on them. In this study, it is used from tariffs related to domestic customers who include 7 step and they are reported in table 3.

Table 3: Base rate of domestic customers in monthly angry consumption

Price (Rial/kwh)	Consumed energy step per month (kwh)
300	Lower100
350	From100 -200
750	From200 -300
1350	From 300 -400
1550	From 400 -500
1950	From 500 -600
2150	upper 600

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Calculation method of customers, bill is such that the off-peak tariff is extracted from consumer consumption steps and based on those initial cost is calculated for total consumption, then in peak periods, 300 Rial/kwh is added to the calculated cost and 150 Rial/kwh is subtract from it in low periods. Namoly in peak periods 300 Rial / kwh is added to off-peak tariff and in low periods, 150Rial / kwh is reduced from off-peak tariff. Iran Ministry of energy was reported that average domestic consumption is 250 kwh. In this study, final step rate is 250 that are equal to 750 Rial / kwh and this rate is considered as off-peak tariff. Here, the peak tariff is 1050 Rial / kwh and low-load tariff is 60 Rial / kwh.

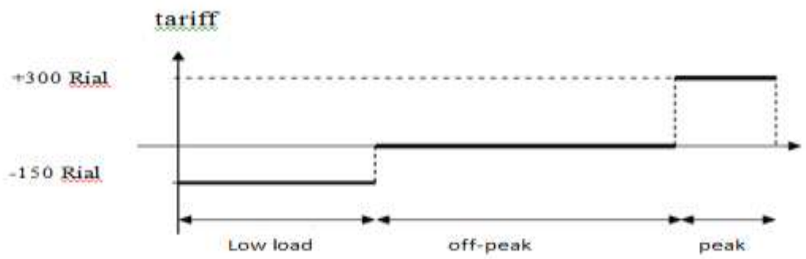

Figure 6: Values of TOU tariff in hour of a day In Iran

Table 2: Self elasticity values and cross elasticity values

	Low load	**Off-peak**	**Peak**
Low load	-0/01	0/014	0/016
Off-peak	0/014	-0/01	0/012
Peak	0/016	0/012	-0/01

The proposed model, considering (**σ**) standard deviation is performed from 0 to 100 percent and also demand response (η) from o to 60 percent is performed that is comparable with previous state in which demand response.
Increase the number of segments in Probability Distribution Function leads to reduce modeling error and to increase computation. In this paper, since the further division of distribution function had not t any impact on simulation results, normal distribution function are dividing to 11 segments and then simulation result are interpreted.
In figure7, reduction percent of daily energy consumption is seen.
As it is clear, these amounts are negative that indicate implementation of this method in Iran leads to increase of daily energy consumption its maximum amount is -1.2 percent that is low. Also Increasing demand response potential leads to further increasing consumption energy. Then the effect of uncertainty in elasticity parameter is more obvious.

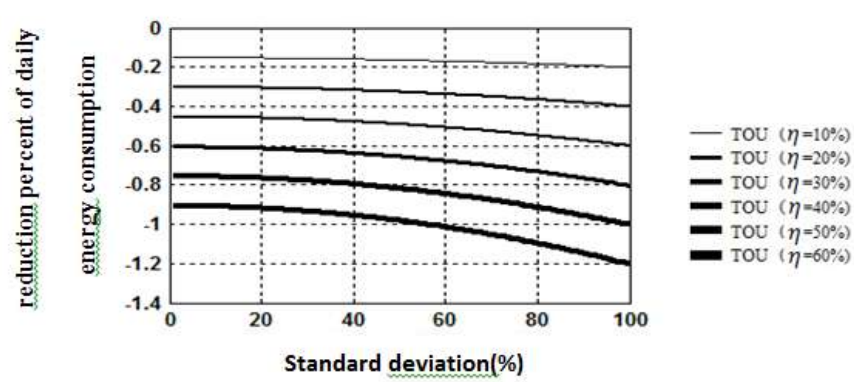

Figure 7: Reduction percent of daily consumption energy in different potential

In figure 8, percentage of consumers, load shifting is seen, i.e. shifting from peak period to other two intervals. Increasing demand response potential, leads to increasing load shifting that is reasonable. Because increasing potential means increasing TOU participants. The participants are participated with installing intelligence or digital metes; hence, it leads to further increasing and shifting from peak period to the other periods. According to figure 8, the maximum load shifting is 2.5 percent that is performed when 60% of subscribers are participated. Increasing uncertainty leads to small load shifting.

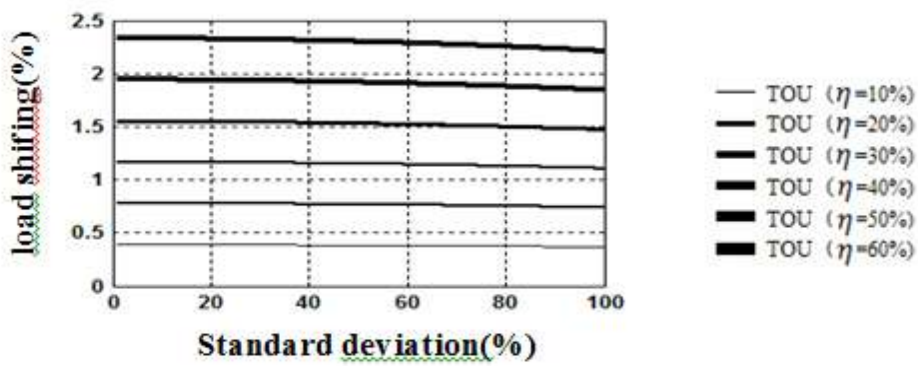

Figure 8: Load shifting percentage with implementation of TOU in different potential values

Figure 9, shows daily reductions percent. This figure shows clearly that implementation of this model helps to peak reduction, hence, it leads to many advantages' for system operator and this can be as a motivational reason for implementation such program. Peak reduction percent increase with raising participant potential and it reaches to0.1 as it highest value. Here there is no effect of elasticity uncertainty.

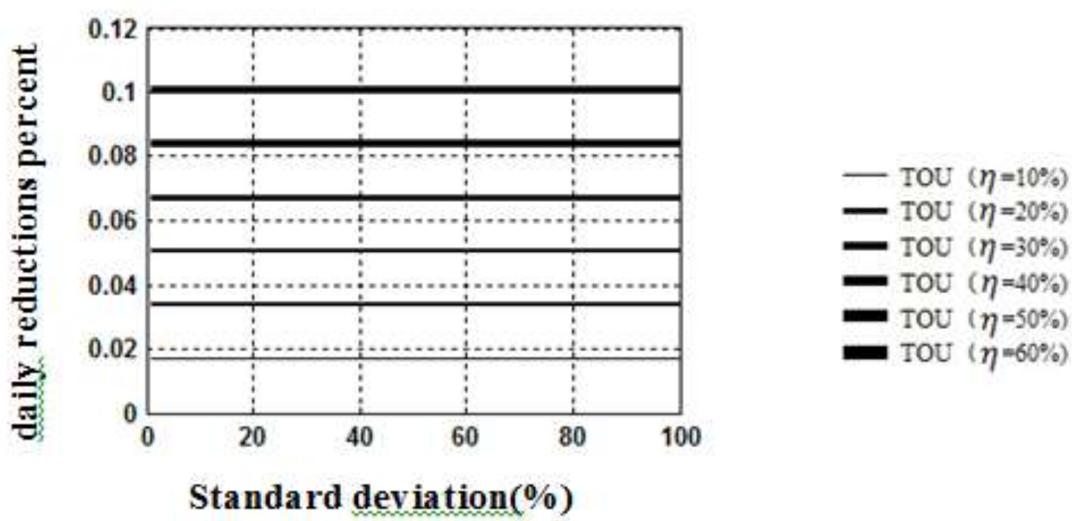

Figure 9: Daily peak reduction percent with implementation of TOU in different potential values

In Figure 10, load factor improvement percent is seen. Increasing demand response potential in 10,20,30,40 and 60 percent result in increasing load factor except the curve related to 50% potential that it has reduced about 0.5 percent of load factor. Increasing responsive customers load curve will be more flat then load factor increases. This figure is completed by the figure 8 that increasing number of consumers results in increasing load shifting. Increasing uncertainty, in contrast with other results, leads to increase of load factor that is very attractive for TOU designers.

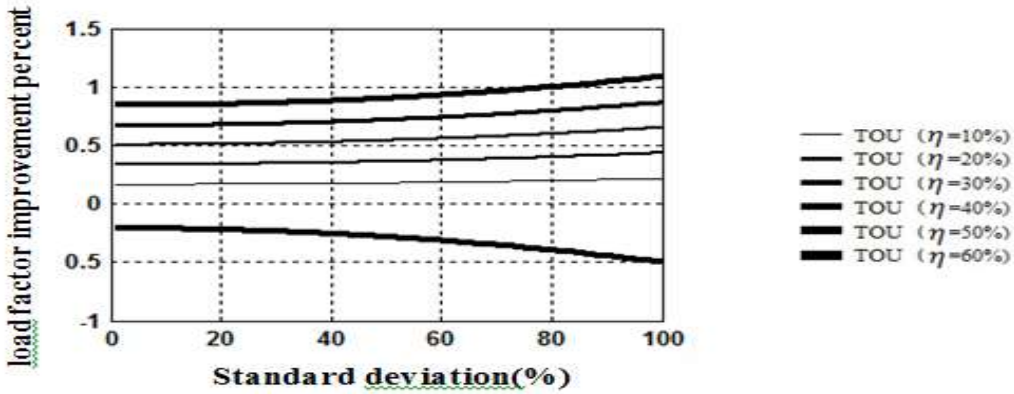

Figure 10: Load factor improvement percent with implementation of TOU in different potential values

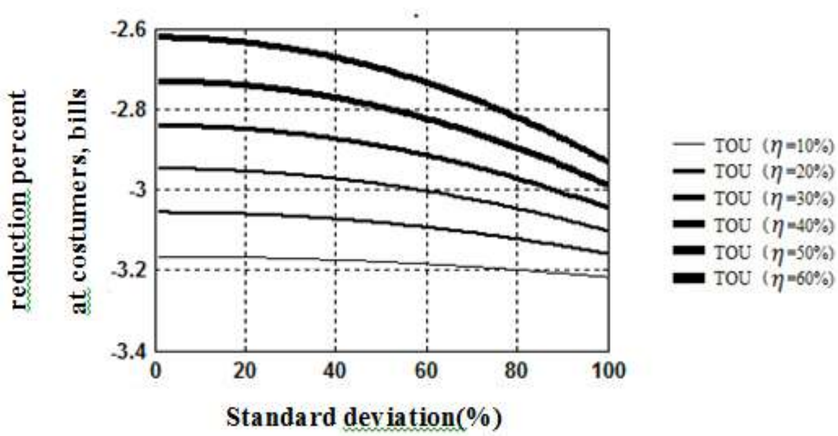

Figure 11: Consumers bills reduction percent with improvement of YOU in different potential

In figure 11, it is seen reduction percent at costumers, bills. As determined, these values are negative, indicating that implementation of this model with the tariff and the scheduling times could result in increasing bills, and hence, it leads to reduce the number of participated customers in long time period. Of course this effect is reduced with increasing potential and indicates that as further consumers use this model, they face with the lower bills.

In another words, increasing participant is useful for all the effect of elasticity uncertainty is more obvious in high potentials.

Conclusion

In this paper, a mathematical model is introduced to predict, the behavior of customers with regard to price elasticity.

Introduced model is adjusted for simulating of customers behaviors in response to TOU as a commend program. Finally, implemented TOU for domestic subscribers in Iran is performed by proposed model and it is evaluated from technically and economically views points.

Simulation results show the strength and Weakness points of TOU implemented in Iran and in these regard designers can use from these results to improve the method. Also operators can be able to predict subscriber's behaviors to proposed TOU tariffs considering uncertainty in their behavior.

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