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A Novel Market Optimization Model in order to Minimizing Environmental Cost Caused by Plants

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Abstract

Nowadays generation capacity in traditional grid depends on fossil fuels and contributes significantly to the increase of pollution emission. In deregulated grids in addition to using demand response programs (DRPs) to reducing the cost of electricity production, peak clipping and improve reliability use of green Plants such as hydro plant, wind plant become widespread. In a smart grid, end users according to their consumption, use one of the DRPs in reduction the cost of energy consumption as well as leads improvement in social welfare. DRPs change the normal pattern of end users consumption that these changes modeled in price elasticity matrix (PEM). The framework of this paper is reducing the cost of pollution generated by plants with a view to minimizing the overall system cost. The objective function presented in this paper is the overall system cost that presented a new method for modeling the DRPs in PEMs, cost of energy produced by independent power producers units and pollution contribute to the plants. The numerical calculation of this paper calculated in a Low voltage residential network and consumers use time of use program (TOU) for load management. The Load Serving Entities (LSEs) aggregate the reduced load compared to normal pattern and participate in the pay as bid (PAB) Stackelberg competition market that called demand side bidding.

Keywords: Demand response, Price elasticity matrix, Time of use program, Demand side bidding, Pollution cost.

1. Introduction

Electricity is the most versatile and widely used form of energy and global demand is growing continuously. Generation of electrical energy, however, is currently the largest single source of pollution emission, making a significant contribution to climate change. To mitigate the consequences of climate change, the current electrical system needs to undergo significant adjustments.

The traditional power system was built up over more than 100 years. It is now one of the most effective components of the infrastructure on which modern society depends. It delivers electrical energy to industry, commercial and residential consumers, meeting ever-growing demand.

Smart grids will provide more electricity to meet rising demand, increase reliability and quality of power supplies, increase energy efficiency, be able to integrate low carbon energy sources into power networks. A smarter grid will provide greater control over energy costs and a more reliable energy supply for consumers. Environmental benefits of a smarter grid include reduced peak demand, integration of more renewable power sources, and reduced pollution emissions. Advanced meters are one of the most important devices that transform a deregulated gird to a smart gird [1].

In 1980s demand side management (DSM) for the first time was presented by ERPI. DSM includes activities that consumers or governments change the normal pattern of using energy in order to increase social welfare. Demand side management is one of the methods that contribute to optimizing the electricity markets. In a smart grid, DSM is called demand response [2], [3]. Demand response (DR) only is possible with direct interaction to consumers that consist of tow general categories, load management and energy management. Load management include methods that changing normal consumption patterns in a short time horizon for the purpose of peak clipping, load shifting and filling the valley. The goal of energy management is appropriate to use of energy [4], [5].

Without the involvement of consumers in DRPs, certainly ultimate goal of DR that reducing peak, can't achieved. Each DRPs need a specific measurement and advanced instrument to save consumption data in addition to send them to Independent system operator (ISO) for proper operation [6], [7]. One of the most important DRPs is Time of use (TOU) program that most residential, office and small commercial end users, tend to use it. The simplest TOU has two mode, peak and off-peak. First time TOU program was used by the industrial in 1956 and then this program widely used by residential end users in 1965. Now more than 1/3 of all consumers in United States use TOU program and experimental result shown that Time of use program with three mode, decrease the peak of load about 10%. [2], [7], [8]

By using TOU program end users change normal pattern of consumption, that ISO can model this change in PEMs. Diagonals Elements indicate own elasticity and other elements define as cross elasticity. [9-12]. In [9] by using Real Time Pricing (RTP) and modeling the change of consumption, the loss reduction in grid is calculated on the IEEE 8500 node but pollution emission by plants is neglected. In [13] with respect to using RTP program, the reduction in normal consumption is modelled to PEMs and the cost of production energy is minimized in all hour a day but pollution of plants is not considered.

Reducing pollution emission is an unavoidable goal. Direct connection between plants and pollution emission; affect a number of critical factors such as reliability and unit commitment problems. DR reduces the use of fossil power plants, which in addition to reducing the ambient temperature will cause consumers to pay lower costs for cooling. Also it is obvious that the rate of installing plants are reduced and less pollution cause less damage to the environment, the ozone layer and global warming [6], [15] .In [16] by modeling DR in spinning reserve, pollution emission is reduced and the peak of Grid is clipped. In [17] by using demand management, pollution is controlled in long range.

In a smart grid, plant and consumers under ISO supervision participate in the market that this method called demand side bidding. In smart grid, these plants called independent power plant (IPP) and the company that aggregate the load reduction and participate in the market called Load Serving Entities (LSEs). In a smart gird ISO administer the bids between IPPs and LSEs.

By using this strategy residential consumers like industrial have the ability to reduce shed load in peak hours. [12]

In this paper, the objective function is total system cost of a smart grid that is a summation of the energy produced by IPPs, the load reduction cost by one LSE and the pollution damage costs .In the second section, briefly introduce PEM and TOU program. In third section modeling are shown. In fourth section the numerical result is presented.

2. A primer on TOU program and PEMs

In this section briefly TOU program and PEM described and it can be seen how TOU program model in a PEM.

A. Time of use (TOU) program

DRPs are apportioned in tow major parts, namely incentive based programs and time based rate programs. Incentive based programs usually used by Consumers with high using energy like industrial end users that have the ability to save the energy in specific range and produce the energy independently. But time based programs used by residential and commercial end users that consume energy in range of kW. Using time based programs are widely used in peak clipping and load shifting. [2] This programs are divided in three general sub categories: Critical peak pricing (CPP) program, Time of use (TOU) program and Real time pricing (RTP) program. In the most of recent work, RTP program uses for residential consumers [9], [13]. But RTP program must be used by end users that consume more than 1 MW. Also price in RTP program indicate the real price of market at each hour that end users for receiving the true price of market must install expensive devices namely advanced metering infrastructure (AMI) [2], [11], [12], [18]. On the other hands In RTP program plants risk are low because end users receive price in a day ahead market. Also the demand of Residential end user are in range of kW, this consumers preferred to use another programs like CPP program and TOU program [2], [18]. As already mentioned, demand response is impossible without the participation of consumers therefore consumers used the program that reduce the cost of energy in addition to improve the social welfare. It can be seen in Fig.1 that end users preferred using TOU program instead of RTP program.

The structures of TOU program are usually in three blocks namely peak, off peak and mid peak. Off peak price is lower than flat price, mid peak price is a bit higher than flat price but peak price is three times higher that flat price. A common TOU summer tariff that residential consumers used widely in Canada is shown in Table 1 [19].

B. Price Elasticity Matrix

One the most important method in modeling demand response is price elasticity matrix. In PEM the diagonal element defined as self-elasticity (Own elasticity) and other elements represents the cross elasticity. Self-elasticity is change in demand at specific ti with respect to price at the same time. Self-elasticity is shown in equation (1).Cross elasticity is change at change in demand at specific ti with respect to price at tj . Cross elasticity is shown in (2). The basic demand is d0 and the basic price is p0. $\Delta d(t_i)$ is change in demand at specific time ti .

Table 1.
Time of Use tariff in a day

Day band	***Price ($/KWH)***
Off peak	8.3
On peak	17.5
Mid peak	12.8

$$E(i,i)=\frac{(\Delta d(t_i)/d_0)}{(\Delta p(t_i)/p_0)} \tag{1}$$

$$E(i,j)=\frac{(\Delta d(t_i)/d_0)}{(\Delta p(t_j)/p_0)} \tag{2}$$

Each column of PEM represents the period of changing in consumption by one price block throughout a day, owing to the change in price at the block instant corresponding to the column number. The total change in load at time ti due to change in price throughout a day can be obtained by adding the entire row. The total change in load at time ti due to change in price throughout the day in TOU program shown in (1). Also with respect to step of pricing in DRP, PEM will be in order of step*step. For a TOU scenario that has a three steps varying, PEM will be in order of 3*3 [2], [8], [9].

$$\Delta d(t_i)=\sum_{j=1}^{3} E(i,j)*(\frac{\Delta p_{j0}}{p_0})*d_0 \tag{3}$$

$$\begin{bmatrix} \frac{\Delta d(of)}{d0_{of}} \\ \frac{\Delta d(p)}{d0_p} \\ \frac{\Delta d(mp)}{d0_{mp}} \end{bmatrix} = \begin{bmatrix} E(of,of) & E(of,p) & E(of,mp) \\ E(p,of) & E(p,p) & E(p,mp) \\ E(mp,of) & E(mp,p) & E(mp,mp) \end{bmatrix} \begin{bmatrix} \frac{\Delta p(of)}{p0_{of}} \\ \frac{\Delta p(p)}{p0_p} \\ \frac{\Delta d(mf)}{p0_{mp}} \end{bmatrix} \tag{4}$$

With respect to (1), (2), (3) the extensive form of PEM in TOU program is mid matrix in Equation (4). For instance the first row in (1) is overall change of demand in off peak divided by off peak basic demand $d0_{of}$ .First column consist of elasticity with respect to price in off peak. Also second and third columns consist of elasticity with respect to price in peak and mid peak respectively.

C. Classification of PEMs by Consumer Behaviours

In Smart grids with respect to smart devices that installed in smart houses, end users decide to shift or shed the normal consumption pattern by influence of energy price data. Therefore end users decide to shift their load to another hour or shed the load at a specific hour. The ability of end users to shift the normal consumption except shedding, depend on devices like smart thermostat or on site generation. Also Fixed load are inelastic to price and must be shed but elastic load can be shifted to another period during a day. By definition of PEM in earlier section, end users according to price data and the ability to change the normal consumption by TOU program are classified into six category:

- Curtailable load: This consumers shed percentage of their consumption in off peak, mid peak and peak period by the price in the off peak, mid peak and peak respectively.
- Forward shifting end users: End users preferred using energy in hours that energy price decreased.
- Backward shifting end users: These end users shifting their consumption earlier.
- Flexible end users: These end users moving their consumption over a long range in a day.
- Real world end users: This end users moving their consumption with a same change over all cross elasticity.
- On site storage: These end users reduce their consumption in a specific time and using energy from their installed storages.

PEM in Real world, on site storage and flexible end users are approximately similar. In this paper end users modeling in PEM are considered according to Curtailable load, forward shifting, backward shifting and flexible end users scenarios.

3. Modeling

The goal of this paper is minimizing the objective function as total system cost. The total system cost is summation of the energy produced by independent power plant (IPP) cost, the load reduction by Load Serving Entities (LSE) cost and the pollution cost generated by IPPs. The LSE aggregate the reduced load in each hour and participate in a Stackelberg competitive market with other IPPs with pay as bid situation. In the Stackelberg market, LSE first participate in the market and IPPs are the followers. It is obvious that using DR program shift load from peak and mid peak hours to off peak. Also TOU program may reduce the demand in mid peak hours. Therefore first the effect of DR program must be calculated on the load profile by using (3). In this paper supposed that all of the end- users are residential and using TOU program. Also one LSE aggregate the reduction load in the test grid. In hours that demand is lower than the demand before TOU implementation, LSE participate in the market. Also in hours that demand increased, only power balance is changed.

A. Problem formulation

Equation (5) is the objective function of developed model based on overall system cost. In this function optimization is done at each hour in a specific day.

$$\sum_{t=1}^{t=24}\left\{\left[\left(\sum_{i=1}^{i=3} C_{i,t}^{IPP}+C_t^{LSE}\right)*(1-f^{pl})\right]+f^{pl}*C_t^{pl}\right\} \quad (5)$$

Equation (5) shows the total system cost and includes four terms that f^{pl} is defined as pollution factor. If $f^{pl}=constant$ the pollution emission is considered in total system cost and if $f^{pl}=0$, the pollution is not considered and similar the others work. Also as f^{pl} increased, the effect of pollution in total system cost is increased. In this paper for considering pollution in the overall system cost, $f^{pl}=0.3$ assumed. Three other terms in objective function are in follow:

$C_{i,t}^{IPP}$: The cost of generated power by independent power plant in each hour of a day. This term is defined as (6) and C_i is bid imposed by IPP.

$$C_{i,t}^{IPP}=C_i*P_{ti} \quad (6)$$

C_t^{LSE} : The cost of reduction demand by LSE in each hour of a day. This term is defined as (7) and Bj is bid imposed by LSE.

$$C_t^{LSE}=Bj*D \quad (7)$$

C_t^{pl} : Pollution emission generated by IPPs consist of gases SO_2 and NO_x that defined as equation.6

$$C_t^{pl}=\sum_{i=1}^{i=3}\{\, P_{i,t}^{SO_2}*(u_{i,t}^{IPP},p_{i,t}^{IPP})* C^{SO_2}+P_{i,t}^{NO_x}(u_{i,t}^{IPP},p_{i,t}^{IPP})*C^{NO_x} \quad (8)$$

In (8), C^{SO_2} and C^{NO_x} terms are the coefficient of environmental cost of SO_2 and NO_x respectively and C_t^{pl} is cost that IPP should pay to independent system operator for every kg pollution produced. The environmental cost coefficient of pollutants are assumed to be 0.5 \$/kg for SO_2 emissions and 1\$/kg for NO_x emission.

Also $P_{i,t}^{SO_2}$ and $P_{i,t}^{NO_x}$ are the functions of pollution that written as (9), (10) that first piecewise linearization approximation method considered. Pollution data are assumed as presented in table 2. [6].

$$P_{i,t}^{SO_2}=IC_{SO_2}*(P_i-P_{\min})+VC_{SO_2} \quad (9)$$

$$P_{i,t}^{NO_x}=IC_{NO_x}*(P_i-P_{\min})+VC_{NO_x} \quad (10)$$

In this paper 3 IPPs considered: one Hydro power plant, one Oil power Plant and one Gas Power plant. Energy bidding information of these IPPs is shown in table 3 [6].

Also one LSE considered that aggregating reduced load by residential end users and participate in market. Residential behavior in TOU program modeled in PEM that LSE by using this matrix, participate in market in each hour. By using matrix presented in (4), Residential behavior is presented as Table 4-7 [19].

In this paper residential behavior modeled in four different scenario that presented in Table 4-7. Also the bidding price of LSE is assumed 20\$/Mwh.

Table 2.
Pollution emission coefficient

IPP	IC_{NO_x} (kg/h)	VC_{NO_x} (kg/h)	IC_{SO_2} (kg/h)	VC_{SO_2} (kg/h)
Hydro plant	0	1	0	1
Gas plant	2.3	6.6	.9	1
Oil plant	2	31.2	11.5	18.5

Table 3.
Bidding information of IPPs

IPP	Bidding Price (\$/MWH)	Min production (MW)	Max production (MW)
Hydro plant	11.25	10	20
Gas plant	39.5	2.4	6
Oil plant	28	15	50

Table 4.
Modelling Curtailable end user behaviour in PEM

PEM	Off peak	Peak	Mid peak
Odd peak	**-0.2**	**0**	**0**
Peak	**0**	**-0.2**	**0**
Mid peak	**0**	**0**	**-0.2**

Table 5.
Modelling forward shifting end user behaviour in PEM

PEM	Off peak	Peak	Mid peak
Odd peak	*-0.2*	*0*	*0*
Peak	*0*	*-0.2*	*0*
Mid peak	*0.1*	*0.1*	*-0.2*

Table 6.
Modelling backward shifting end user behaviour in PEM

PEM	Off peak	Peak	Mid peak

Odd peak	*-0.2*	*0.1*	*0.1*
Peak	*0*	*-0.2*	*0*
Mid peak	*0*	*0*	*-0.2*

Table 7.
Modelling flexible end users behaviour in PEM

PEM	*Off peak*	*Peak*	*Mid peak*
Odd peak	-0.2	0.1	0.05
Peak	0.1	-0.2	0.1
Mid peak	0.5	0.1	-0.2

B. Constraints

The numerical calculation was run for hours 1 to 24 in a specific day by step of 1 hour. The constraints used in calculation presented as follow:

$$\sum_{i=1}^{i=3} P_{it} = P_t \tag{11}$$

$$P_i^{\min} \le P_{it} \le P_i^{\max} \tag{12}$$

$$D_i^{\min} \le D_{it} \le D_i^{\max} \tag{13}$$

$$D_t^{\max} = \sum_{j=1}^{3} E(i,j) * (\frac{\Delta p_{j0}}{p_0}) * d_0 \tag{14}$$

The demand generation balanced at each hour is presented in (11). After using TOU program, load curve changed. Therefore Pt must be calculated again in hours that LSE don't participate in the market. Minimum and maximum load Reduction that imposed by LSE at each hour must meet (12).

By using (1) and (4) maximum load reduction has been available in LSE at peak, off peak and mid peak. $D_i^{\max}$ is calculated based on (14). Minimum load reduction was assumed 0.

4. Numerical Result

The objective function is solved via CPLEX solver with GAMS software. It is obvious that objective function is a unit commitment problem with pollution emission constraint that generated by IPPs. Also it is assumed that market is located in Stackelberg competition.

A. Test Feeder

As described earlier, TOU program affect end users load profile and change the normal pattern [20]. TOU is introduced a benchmark LV feeder that shown in Fig.1. The benchmark LV feeder load profile is presented in Fig.2.

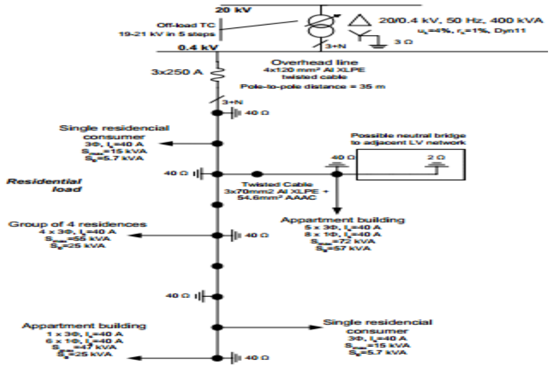

Fig. 1. Benchmark of LV feeder in Smart grid form

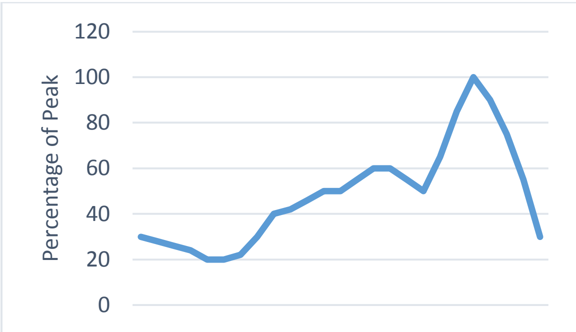

Fig. 2. Load profile of benchmark LV feeder in one day

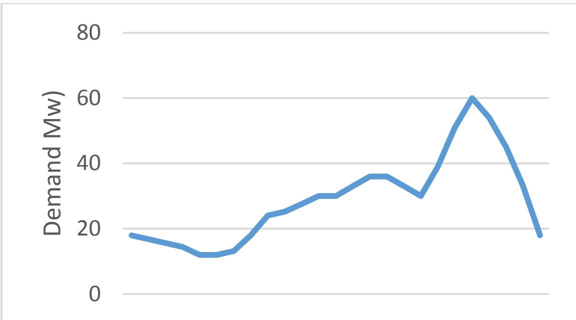

Fig. 3. Study case load profile in one day

In this paper a developed low voltage feeder based on the introduced benchmark is used as the test system. Residential load profile in this paper is presented in Fig.3. Fig.3 represents the load profile curve that is divided into three different periods, namely off peak period (11:00 pm–11:00 am), mid peak period (11:00 am–6:00 pm and 10:00 pm-11:00 pm) and peak period (6:00 pm–10:00 pm). Load factor in proposed test system before transform the system to smart grid is 0.49.

A. Results

In order to evaluate the proposed objective function, three scenarios are considered:

- Case I: This case is the base one that end users using flat rate price. In this case the ratio of peak demand to valley demand is five. IPPs generation are calculated at each hour.

- Case II: In this case end users using TOU program and load reduction is calculated by PEMs in each hour based on traditional load profile. LSE participate in the competitive market via IPPs and IPPs generations are calculated at each hour.
- Case III: In this case, LSE and IPPs participate in the market with pollution emission constraint. IPPs generation are calculated at each hour.

Fig.4 shows the residential load profile before DR and after using TOU program by end users at each scenario. As shown in Fig.3, after implementation TOU program, peak load in Curtailable load end users, forward shifting end user, backward shifting end user and flexible end user reduce 13%, 9.3%, 13% and 11% and load factor after TOU program become 0. 61 , 0.56 , 0.56 and 0.55 respectively.

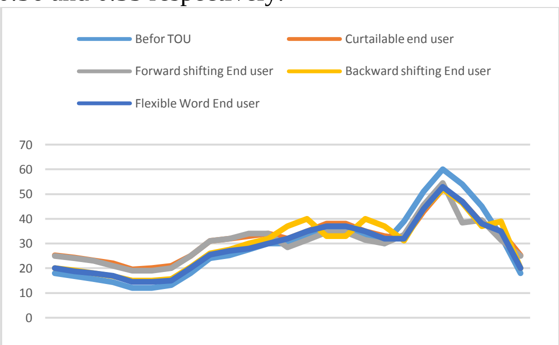

Fig. 4. Residential load profile at each scenario in a day

By using (3) LSE participate in the market in hours that presented in Table 9.

Table 9.
Maximum energy production by LSE

$D_t^{\max}$	***Period***	***Maximum reduction in mid peak (Mw)***	***Maximum reduction in peak (Mw)***
Curtailable load end user	*6pm - 10pm*	*0*	*8*
Forward shifting end user	*12pm-10pm*	*2.5*	*5.5*
Backward shifting end user	*6pm-10pm*	*0*	*7*
Flexible end user	*6pm-10pm*	*0*	*7*

Gas plant generation are presented for Curtailable load end users, forward shifting end user, backward shifting end user and flexible end user in Fig.4, Fig.5 and Fig.6 and Fig.7 respectively.

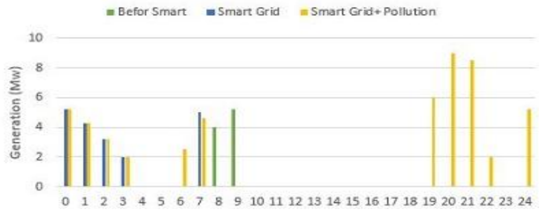

Fig. 5. Curtailable load end user

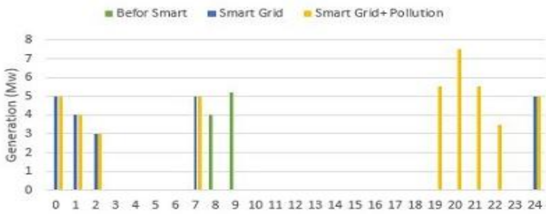

Fig. 6. Forward shifting end user

As it presented in Table 3, Gas power plant bidding is higher than other plants, therefore generation in a system without considering pollution cost is zero in peak hours but when pollution cost is considered in overall system gas plant generating energy. Also changing in gas plant generation during off peak hours is caused by changing demand in normal demand. This changing at unit commitment is shown in Figs. 4-7.

The overall pollution caused by SO_2 and NO_x generated by IPPs in three cases at different PEMs are presented in Fig 8-11. It is obvious that pollution cost in a smart grid by using demand response program is decreased. When the method proposed in this paper for reducing the pollution emission cost is considered, it can be seen that pollution cost is decreased at each scenario.

Fig. 7. Backward shifting end user

Fig. 8. Flexible end user

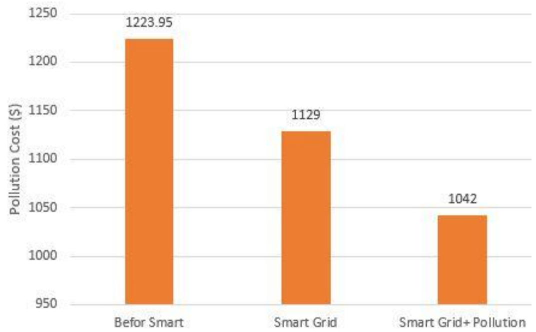

Fig. 9. Curtailable load end user Pollution Cost

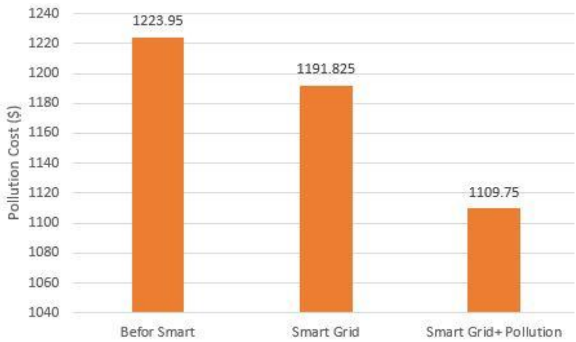

Fig. 10. Forward shifting end user Pollution Cost

5. Conclusion

In traditional markets, overall system cost only is related to the generation cost but in a smart grid LSEs participate in the market in addition to plants. However pollution emission that generated by plants considered in traditional grid and common smart grids. In this paper a novel method for calculating the overall system cost based on reduction in plant pollution is evaluated. The numerical result show that if pollution is noticeable, plant with low pollution generation are in the priority. Also pollution cost is decreased in proposed method related to the common smart grid that using demand response.

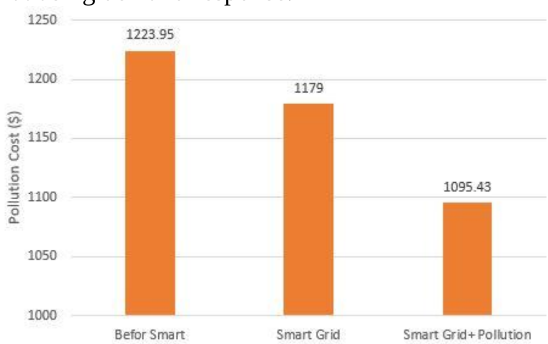

Fig. 11. Backward shifting end user Pollution Cost

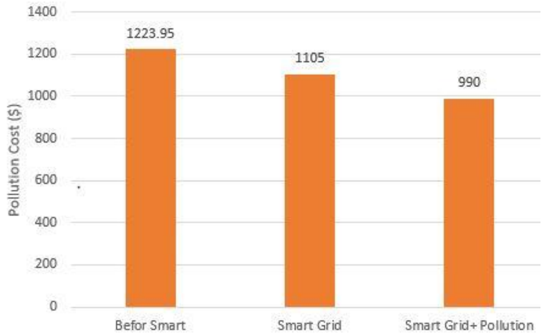

Fig. 12. Flexible shifting end user Pollution Cost

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