Financial Opportunities by Implementing Renewable Sources and Storage Devices for Households Under ERCOT Demand Response Programs Design

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***Abstract*—The Electric Reliability Council of Texas (ERCOT) launched a nodal market in December 2010, aiming at benefiting customers who are willing to curtail or shift their loads to help improve system reliability. Demand response (DR) programs may stimulate users to change their electricity consumption patterns based on electricity prices and incentives. Senate Bill 1125 allows residential and commercial class customers to participate in DR programs alongside industrial customers while reliability standards are maintained. By effectively utilizing renewable sources and energy storage devices, household electricity bills might be reduced since the purchase of electricity, particularly when the price is relatively high, can be replaced by either renewable resources or electricity from energy storage devices. This paper presents different scenarios of implementing photovoltaic systems and Li-based batteries under ERCOT's DR program design for a household in order to reap financial benefits. A typical Texas residential load profile and the locational marginal prices information of ERCOT's real-time market are applied to optimize battery capacity and total revenue. Finally, the calculation results illustrate that by participating in the DR programs, residential users are able to obtain financial benefits.**

***Index Terms*—Demand response (DR), Electric Reliability Council of Texas (ERCOT), energy storage, nodal market, renewable energy.**

NOMENCLATURE

ERCOT	Electric Reliability Council of Texas.
DR	Demand response.
DRG	Distributed renewable generation.
LMP	Locational market price.
PV	Photovoltaic.
REP	Retail electric provider.
RTM	Real-time market.
SB	Senate bill.
TDSP	Transmission and distribution service provider.
VLR	Voluntary load response.

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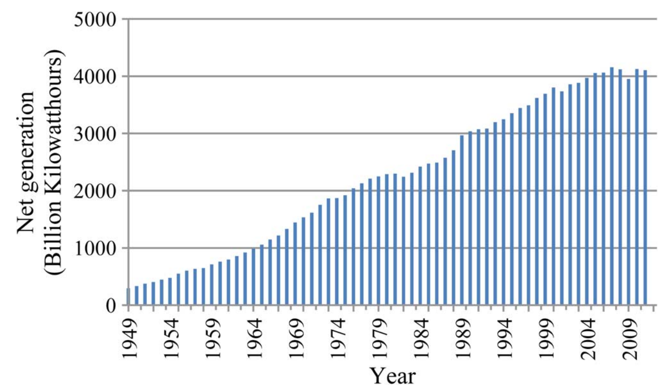

Fig. 1. Net electricity generation of the United States from 1949 to 2011.

I. INTRODUCTION

THE CONTINUOUS growth of electricity demand reveals challenges to the utility industry posed by limited resources and environmental impacts. Fig. 1 shows the net electricity generation of the United States from 1949 to 2011 based on the data published by the U.S. Energy Information Administration, from which an upward trend can be seen, and net generation is projected to exceed 5000 billion kWh by 2035 [1], [2]. It usually takes 5–10 years to complete a nuclear plant [3]; 6 years to build a coal plant, and the construction lead time for a natural gas combined cycle power plant is about 3 years [4]. Moreover, this time-consuming process is constrained by many external factors, including government policies, economic conditions, and environmental concerns. Possible alternatives include improving energy efficiency, adopting DRG, participating in DR programs, etc.

Conventionally, the capacity of an electrical system is designed according to peak demand, whereas DR aims to guide load consumption in response to generation conditions [5]. By managing load profiles, customers may change their consumption patterns to reduce the peak and lower generation capacity requirements. More than being a substitute for new generation capacity, DR is defined as "providing wholesale and retail electricity customers with the ability to choose to respond to time-based prices and other types of incentives by reducing and/or shifting usage, particularly during peak demand periods, such that modifications in customer demand become a viable option for addressing pricing, system operations and reliability, infrastructure planning, operation and deferral, and other issues" by the U.S. Demand Response Coordinating Committee [6].

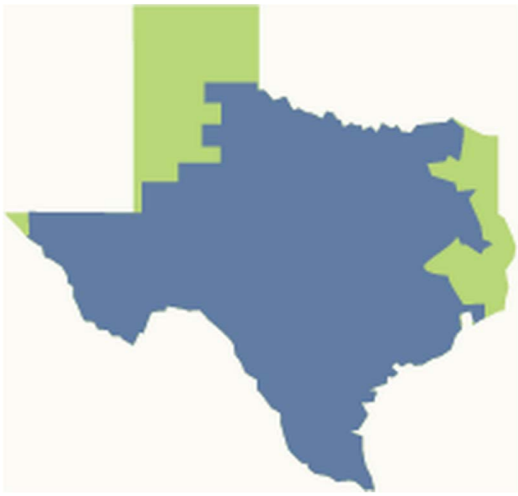

Fig. 2. ERCOT region [10].

SB 1125 was approved by the Texas Legislature in 2011 and has been in effect since September 1, 2011. SB 1125 is an act related to energy efficiency goals and programs, public information with regard to energy efficiency programs, and the participation of loads in certain energy markets [7]. One purpose of SB 1125 is to qualify residential and commercial customer classes for participation in DR programs, which are currently limited to industrial classes on the condition that reliability standards are maintained. SB 1125 also encourages utilities in the ERCOT region to facilitate REPs in the delivery of efficiency programs and DR programs, including programs for demand-side renewable energy systems, which use DRG [8], [9].

Since similar laws may be implemented in other markets in the future, this paper uses ERCOT's DR programs and SB 1125 as an example to implement PV systems and Li-based batteries for a household to reap financial benefits under different scenarios. Residential load profile information and LMP information of ERCOT's RTM are used to optimize battery capacity and total revenue in order to maximize financial opportunities. In this paper, Section II describes the ERCOT nodal market and DR programs, and Section III focuses on solar energy conditions in Texas and incentive programs. Energy storage devices are compared and selected in Section IV. Three scenarios of implementing DRG and energy storage devices while considering nodal market price information are discussed in Section V. Section VI draws the final conclusion.

II. ERCOT Nodal Market and DR Programs

A. *ERCOT Nodal Market*

ERCOT manages 85% of electric power load and 75% of the land area in Texas where 23 million customers are served [10], as shown in blue in Fig. 2. In September 2003, the Public Utility Commission of Texas required ERCOT to develop a nodal wholesale market to improve market and operation efficiency through more rapid and granular pricing and scheduling of energy services. On December 1, 2010, ERCOT launched a comprehensive nodal market where electric grid congestion and price information will be captured in more than 4000 nodes [11]. Compared with the previous zonal market, a nodal market has the following advantages: 1) price signals are more detailed and generation dispatch is more efficient; and 2) local congestion can be reduced [12]. Nodal price is the cost at a given node to provide the next megawatt of power; it includes three parts, namely, marginal cost of generation, marginal cost of losses, and marginal cost of transmission congestion [13]. The ERCOT nodal market consists of several types of day-ahead and real-time operations. In RTM, the price of the electricity at a single node varies along the day, whereas there could be substantial differences in electricity prices at different nodes. The LMP information RTM in two typical time spots are plotted in Fig. 3. Fig. 3(a) and (b) shows the RTM price at 19:40 October 7, 2012 and 11:15 October 8, 2012, respectively [14]. In Fig. 3(a), the highest price is around 51.99\$/MWh, and the lowest price is less than 18.29\$/MWh, whereas the price

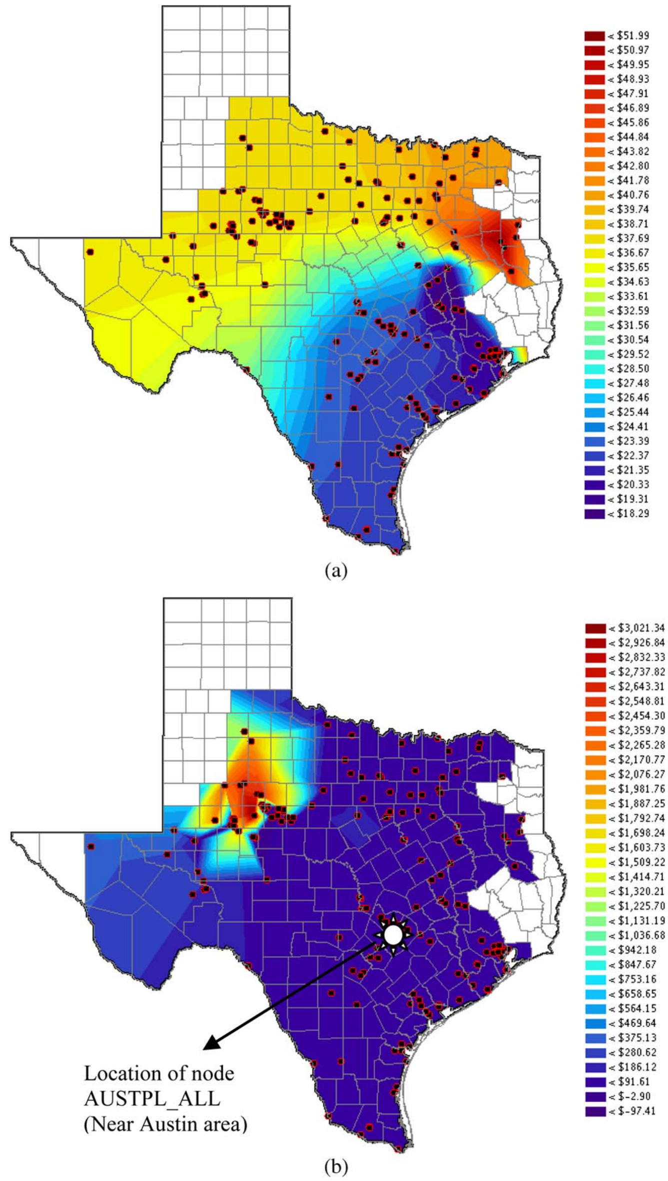

Fig. 3. ERCOT locational marginal pricing in RTM [14]. (a) Price information at October 07, 2012 19:40. (b) Price information at October 08, 2012 11:15.

TABLE I
DEMAND-SIDE PARTICIPATION IN ERCOT [15]

Resource Type	Resources or Service that can be Provided	Requirements
Voluntary Load Response	Curtailment or reduction in response to load zone price or other factors	❖ Metering and/or curtailment technology defined in retail electric provider contract
Day Ahead Market bids and response	Load may choose to curtail or reduce consumption in response to prices bid in the Day Ahead energy market	❖ Day Ahead Market Pricing ❖ Metering and/or curtailment technology defined in Retail Electric Provider contract
Real Time Market and passive response to price	Load may choose to curtail or reduce consumption in response to prices in the Real Time energy market	❖ Real Time Pricing ❖ Metering and/or curtailment technology
Load Resources	Various ERCOT Ancillary Services	❖ Interval Data Recorder meter ❖ Telemetry ❖ Qualification

range is from −97.14$/MWh to 3021.34$/MWh in Fig. 3(b). The extremely high price shown in Fig. 3(b) in West Texas is caused by network congestion. The tremendous change in LMP displays the financial opportunities of exploiting price variations if electricity could be kept in energy storage devices when the price is relatively low and consumed or even sold back to the grid when the price reaches a certain level.

B. VLR in ERCOT Market

Sustaining the reliability and managing the operation of the grid are the principal missions of ERCOT, whereas supporting the day-ahead market is another task [15]. ERCOT's objective is to "ensure that sufficient resources in the proper location and required ancillary services have been committed for all expected load on a day-ahead and real-time basis" [16]. Resources include both generation resources and load resources. For the load resource, customers will be rewarded by changing consumption patterns to facilitate system reliability under ERCOT's nodal market environment. Different load responses and demand-side programs are summarized in Table I.

VLR, which is also referred to as "passive load response" or "self-directed load response," is the customers' self-motivated behaviors of adjusting the levels of consumption according to stimulus from market prices. More flexible than other programs, VLR does not obligate customers to respond to the market as a load source; however, if the customers would like to behave as a load source, further financial compensation could be exploited depending on the contracts with the REPs [15]. The main financial opportunities of VLR can be gained from changing consumption patterns in order to reduce electricity bills, such as reducing electricity usage when prices are high. In RTM, customers can request their REPs to provide ERCOT's real-time operation prices; since the price data can be accessed from the public website, customers can accommodate their consumption behaviors to achieve financial benefits [9], [17]. Fig. 4 shows the consumption pattern of a residential customer after enrolling in a program that provides free electricity between 22:00 and 6:00 the next day. The customer utilized the free energy at night by moving some nontime-sensitive load to 22:00 and later.

III. URBAN AREA RENEWABLE ALTERNATIVE: SOLAR POWER

A. Solar Resources in Texas

The cost of renewable generation continues to decrease. In urban areas, PVs are most widely used for exploiting solar energy because they are CO_2 emission free and installation locations, such as house roofs and building surfaces, are easily found [18]. Its lack of noise pollution, long life span, and low maintenance requirements make PV a preference among renewable resources in urban areas.

There are abundant solar resources in Texas. In general, the daily and seasonal demands of Texas are synchronous with solar power output, which makes it feasible to cover a large portion of energy requirements using solar resources under the condition that the cost of renewable generation can be reduced as technologies develop [19]. The historical average module costs [20] are shown in Fig. 5.

B. Texas Solar Rebates and Incentives

Although there is no government legislation in Texas that requires utilities to provide net metering to facilitate renewable energies, SB 20 launched a goal to achieve an additional 5880-MW renewable energy capacity by 2015; 500 MW are mandated to be nonwind resources, which indirectly promotes solar energy. A further target of additional renewable energy capacity is set to be 10 000 MW by 2025.[1] In order to encourage the installation of PVs, federal, state, local, and private incentives and rebates offer numerous economic stimuli such as tax credits, tax deductions, property tax relief, purchase incentives (rebates), production incentives, etc.; and among them, a significant portion is designed to benefit residential application [21], [22]. In different cities, various incentives are offered to cut installation costs and to offer rebates per kilowatthour of solar generation, making PV installation in households feasible.

IV. ENERGY STORAGE DEVICE SELECTION

The day–night cycle causes extremely unevenly distributed PV output over the course of 24 h. Energy storage devices offer possible solutions to improve the effective utilization of solar power by leveling peak demand and shifting excess energy to the time when electricity is needed, and sunlight is not available. Nowadays, many types of storage devices are available, and several criteria must be considered when making choices,

[1] *Texas Renewable Portfolio Standard.*

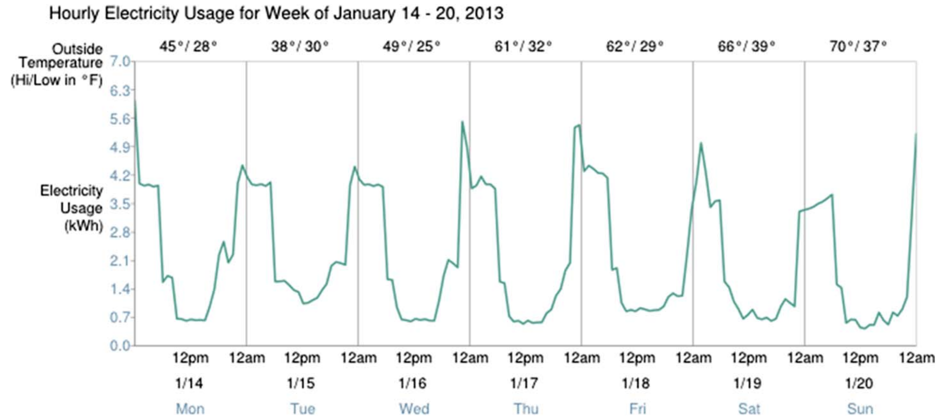

Fig. 4. Power consumption pattern of a residential customer with incentive program.

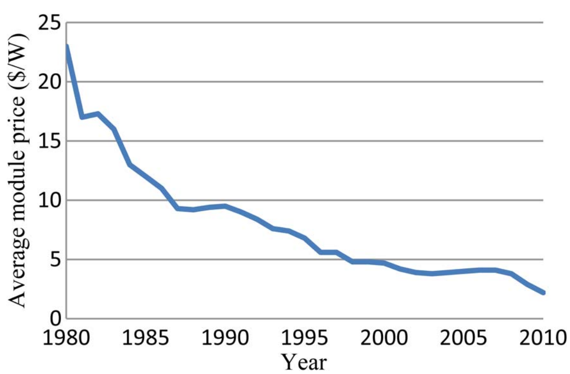

Fig. 5. Cost of solar PV generation [20].

such as application type, reliability, feasibility, power rating, storage capacity, electrical efficiency, lifetime, response time, and costs [23]. For residential usage, batteries are preferred since they can be located inside the building. The energy is stored in electrochemical form, and the batteries are connected to the grid by compatible auxiliary devices, such as power converters and inverters. Typically, the battery system has 60%–80% efficiency, and its response time is approximately 20 ms [24].

Though batteries have good characteristics, their high cost presents a major obstacle to large-scale application. Ongoing research aims to enhance capacity and lower costs. New technologies under development include Li-based, sodium–sulfur, nickel–cadmium, nickel–metal hydride, and zinc–bromine batteries [25], [26].

The primary goal of selecting storage devices in this paper is market success. Thus, the main objectives are to: a) reduce cost; b) increase performance; c) reduce weight and volume; and d) increase tolerance to abnormal conditions. Li-based batteries have a wide range of uses such as powering electric vehicles and aerospace applications because of their high energy density. Li-based batteries also have a satisfactory energy-to-weight ratio, low charge loss, and no memory effect.[2] Therefore, a Li-based battery is used for this study and the chosen model is currently under development, supported by the U.S. Department of Energy under American Recovery and Reinvestment Act cost-shared grants. The battery is expected to be available by 2014 [27]. The life span of the battery is expected to be 15 years with a cost of $3400 and a capacity of 11.6 kWh.

[2]"Energy efficiency."

V. Financial Opportunities Analysis: Case Studies

In order to adopt the ideas of SB 1125 and reap the financial benefits, DR programs design in ERCOT is extended to residential customers for the studies in this paper.

The financial benefits calculation in this paper is based on daily information; thus, the cost of batteries is also scaled to daily intervals. By calculation, the battery cost per day per kilowatthour is $0.053. This cost is a key factor when seeking optimal storage capacity.

Though PV installation is a large investment for residential customers, different incentives and rebate programs described in Section III have made this expense affordable. For example, the residential customer discussed in this paper took advantage of local and federal incentives, including a solar panel rebate of 3$/kW from the local utility; a rebate of 0.8$/kW for participation in a demonstration project; and a 30% federal tax incentive [28]. Assuming a lifetime of 25 years for the solar panel system, the approximate daily cost for each kilowatt installation is $0.04. Considering the fact that the electricity retail price will actually be higher than the wholesale price, there will be sufficient savings after installation to compensate for this daily cost. Another example can be found at UT Arlington: the installation of 384.93-kW solar panels atop Park North and Park Central parking garages cost the university $368 000, but Oncor provided a $390 000 rebate [29]. From these two examples, the cost of PV installation can be reduced to a negligible level via incentives and rebate programs. Therefore, the solar panel installation cost is not considered in this study.

Three case studies of implementing PV systems and Li-based batteries under ERCOT's DR program's design for a household will be discussed in the following sections. The ultimate target of the studies is to explore financial opportunities in RTM. A typical Texas residential load profile and the LMP information of ERCOT's RTM are applied to calculate the battery capacity and total revenue.

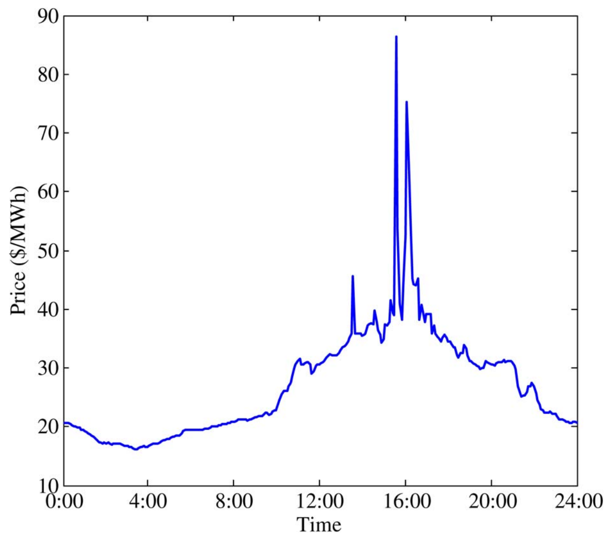

Fig. 6. Locational marginal price in RTM at node AUSTPL_ALL. Date: July 24, 2012.

A. ERCOT RTM LMPS

The wholesale price information of the ERCOT RTM can be accessed through [30]. The data are posted every 5 min for all the current 544 nodes. The price information for a node called AUSTPL_ALL near Austin [location shown in Fig. 3(b)] in July 24, 2012 is plotted in Fig. 6 as an example. July 24, 2012 is a common summer day, with a temperature range between 77 °F and 96 °F. From Fig. 6, it is shown that the prices before 11 A.M. and after 9 P.M. were relatively low, all less than 30$/MWh, whereas the peak price appeared at around 4 P.M., reaching more than 80$/MWh. The prices varied more than four times within a single day.

In a VLR program, load customers are allowed to request their REPs to provide the prices that ERCOT publishes during real-time operations [17]. In customers' monthly electricity bills, the charges coming from the TDSPs for operating and maintaining power facilities are included regardless of which REP is chosen; the TDSP charge usually costs several cents per kilowatthour [31]. In this paper, the main interest is to employ the fluctuations of the price signals. Thus, the electricity prices applied to the residential customers are assumed to be the wholesale electricity price without the TDSP and other charges, since they will not affect the prices variation patterns. The prices are assumed to remain constant for 5 min before new data are published.

B. Load Profile and PV Generation Curve

The per-minute load consumption and PV generation data within 24 h on July 24, 2012 from a typical Texas household near node AUSTPL_ALL are used for the analysis in this paper, and the data are shown in Fig. 7. With the nodal price at AUSTPL_ALL and load consumption data, the electricity cost C_0 for this single day can be calculated by

$$C_0 = \int_0^{1440} p_M(t) \cdot P_L(t) \cdot \frac{1}{60}\, dt \tag{1}$$

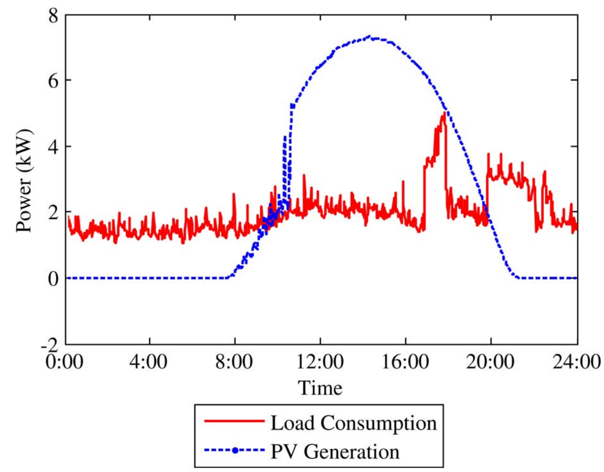

Fig. 7. Load consumption curve and PV generation curve of a typical Texas household. Date: July 24, 2012.

where C_0 is the total cost; $p_M(t)$ is the LMP at node AUSTPL_ALL for each minute in \$/kWh; $P_L(t)$ is the load consumption power in kilowatt and is assumed to be constant within each minute. C_0 is calculated to be \$1.8645.

This household has installed PVs, which provide power during daytime between 8 A.M. and 9 P.M. The demand is around 2 kW during most of the day before the peak hour around 5 P.M. Since the output of PVs exceeds load consumption during most of the day, batteries might provide a solution to shift the excess part for night use. Because battery cost is an important factor, different scenarios involving PV and battery installation are discussed.

C. Case Studies

As aforementioned, the cost of PV systems is not considered in this paper. Several other assumptions for the battery systems are made: i) perfect efficiency; ii) maintenance free; and iii) no auxiliary devices (e.g., inverters) cost. In addition, in all the cases, electricity feeds back from the user side to the grid side is designed to be minimum and is not metered.

Scenario One: PV Only: In this case, PVs are installed in the household while no batteries are included. When there is no output from PVs, electricity is imported from the grid; when PVs have power output, it will be consumed before grid power. The electricity cost C_1 for July 24, 2012 with PV installed can be calculated by using

$$C_1 = \begin{cases} \int_0^{1440} p_M(t) \cdot [P_L(t) - P_{\mathrm{PV}}(t)] \cdot \frac{1}{60}\, dt, & \text{when } P_L > P_{\mathrm{PV}} \\ 0, & \text{when } P_L < P_{\mathrm{PV}} \end{cases} \tag{2}$$

where $P_{\mathrm{PV}}(t)$ is the PV power generation in kilowatt at each minute and is assumed to be constant for the whole minute. C_1 is equal to to \$0.8826 after calculation.

Compared with C_0, the electricity cost C_1 has been reduced by 53%, showing that installing PV is a cost-effective solution. This is because PV output covers most of the power consumption in daytime, reducing the total energy imported from the grid, particularly when the LMP is high during peak

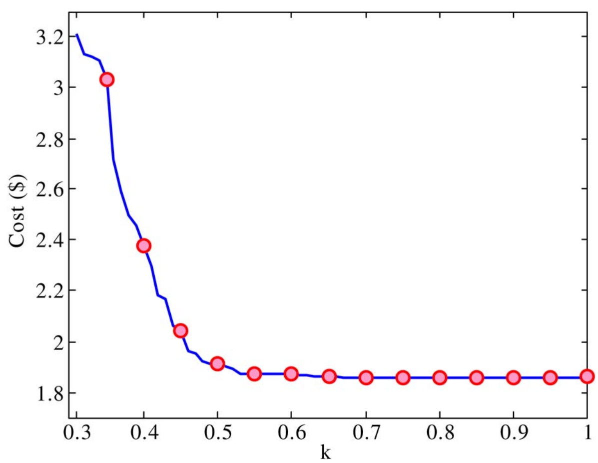

Fig. 8. Electricity cost for July 24, 2012, according to different values of the threshold factor k.

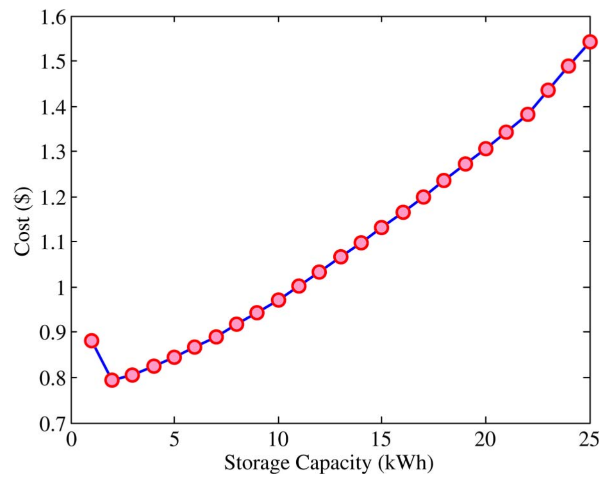

Fig. 9. Electricity cost when different storage capacity is chosen.

hours. Therefore, installing PV is a good solution for reducing electricity bills.

Scenario Two: Batteries Only: The main idea of this scenario is to install energy storage devices (batteries in this study) in a household and store the electricity in the batteries when the LMP is low. Instead of importing electricity from the grid during peak hours, energy in the batteries will be used to reduce the total cost. One key factor that influences overall revenue is the capacity of the battery system since the cost of batteries is still relatively high for large-scale applications.

A threshold price that clarifies a boundary between the high price and the low price is defined to determine whether the batteries absorb or deliver electricity. A threshold factor k is also introduced. When the LMP reaches the threshold price p_{thre}, batteries start to deliver electricity; p_{thre} is defined by

$$p_{\text{thre}} = p_{\text{MAX}} \cdot k \; (0 < k < 1) \tag{3}$$

where p_{MAX} represents the maximum price among the day in dollars. For example, p_{MAX} in Fig. 6 is 86.33\$/MWh. When k is chosen to be 0.75, p_{thre} is 72.25\$/MWh. Thus, when the LMP is higher than 72.25\$/MWh, the batteries will support the load. For different values of k, different battery capacities will be required. A lower p_{thre} value results in the need for larger battery capacity.

The total cost of batteries is calculated by the product of the cost per kilowatthour and the total capacity. As mentioned in the beginning of Section V, the cost of the battery used in this paper is 0.053\$/kWh per day. A plot of the total electricity cost as a function of threshold factor k is shown in Fig. 8; k changes from 0.3 to 1 for better visualization. When k is chosen to be a smaller value, the batteries start to absorb energy when the LMP is relatively low, thus a larger capacity is required; however, the cost saved by shifting PV output cannot compensate the investment for batteries, resulting in an invalid solution. As k increases, the cost varies slightly around \$1.86. The minimum cost in this scenario, i.e., C_2, is acquired at \$1.8558 when k is 0.45–0.57.

Compared with C_0, there is not much improvement after installing the batteries because of their high cost. This scenario might become feasible as battery technology develops.

Scenario Three: PV and Batteries: With the installation of both PV and batteries, this scenario is designed to optimize the usage of solar power. The electricity generated by PVs has the priority to supply the load. When PV generation is greater than load consumption, the surplus portion is stored in the batteries; when generation is less than consumption, batteries supply the load before grid electricity is imported. The total cost of this case consists of two parts, namely, electricity cost and battery cost. The total cost C_3 for July 24, 2012 can be achieved by

$$C_3 = \int_0^{1440} p_M(t) \cdot [P_L(t) - P_B(t)] \cdot \frac{1}{60}\, dt + C_B \tag{4}$$

where $P_B(t)$ is the battery output power in kilowatt; and C_B is the battery cost per day in dollars calculated from the product of battery capacity and cost per kilowatthour. As the capacity varies, C_B will also change.

The electricity cost as a function of storage capacity is plotted in Fig. 9. As capacity increases, the total cost drops before it reaches the bottom and then rises again. All the capacity choices that make the total cost less than C_0 are valid solutions. C_3 is chosen to be the minimum value, \$0.7955. This result shows that by installing both PVs and batteries, the electricity cost can be reduced on the condition that a proper storage capacity is chosen.

The comparison of the three different scenarios is shown in Table II. In summary, installing PV is an effective method of cutting electricity bills, and implementing batteries together with PV system brings slightly better results. However, if only batteries are added, they do not significantly reduce the electricity bill. In general, PV installation does provide an alternative for supplying residential load, particularly during peak hours in Texas. Customers are able to get some financial benefits by participating in DR programs. The LMP of the wholesale market is used in this paper since the variation of prices is the main interest; when retail price is implemented where prices are higher, the scenario with battery installation will have better results.

TABLE II
COST COMPARISON FOR THREE SCENARIOS

Scenarios No.	Scenario Design	Total Cost (C)
0 (*Base Case*)	No PV nor Battery is installed, import electricity from the grid	C_0 = \$1.8645
1	Install PV only	C_1 = \$0.8826
2	Install battery only	C_2 = \$1.8558
3	Install both PV and battery	C_3 = \$0.7955

VI. CONCLUSION AND FUTURE WORK

Since similar laws may be implemented in other markets in the future, this paper uses ERCOT's DR programs and SB 1125 as an example to implement PV systems and Li-based batteries for a household to reap financial benefits. Three different scenarios have been studied. Based on the analysis results, the following conclusions can be derived.

1) DR programs at the residential level are win–win policies that can benefit the load customers and relieve grid congestion during peak hours.
2) The financial benefits are largely dependent on customers' load profiles. When consumption habits are changed by shifting some nontime-sensitive load to the time when LMP is low, savings can be made.
3) For the locations where the nodal price variation is larger, the proposed approach in this paper is more attractive.
4) When rebates and incentives are available, installing renewable sources suitable for residential area applications like PV is a clean and cost-effective method of fulfilling home demand.
5) Due to its high cost, installing energy storage devices alone is of little benefit, but PV installation can work as an alternative method for supplying residential load in Texas, particularly during peak hours.

Future work will be performed in two directions.

1) Determine the storage capacity based on the calculation over a longer time span such as one month or one season to maximize profits.
2) More practical constraints such as the efficiency and the maintenance fee of the energy storage devices, the TDSP charge, auxiliary device costs, and changes in customer consumption patterns will be taken into consideration.

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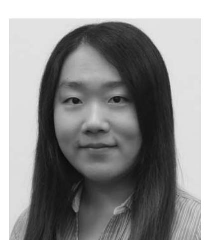

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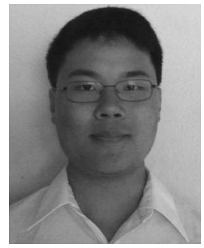

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